Clinton.

IMPERIAL BUREAU OF MYCOLOGY
15 AUG. 1921

Jan
1900.

UNIVERSITY OF ILLINOIS

Agricultural Experiment Station.

URBANA, MARCH, 1900.

BULLETIN No. 57.

THE SMUTS OF ILLINOIS' AGRICULTURAL PLANTS.

The following pages are the result of studies made by the writer during the past five years to ascertain the kinds of smuts infesting our cultivated plants, the injuries inflicted by them, facts in their life histories, and the most practical methods of preventing their ravages. Some of the smuts have been more thoroughly studied than others because of opportunities offered, and the above points of investigation also have varied considerably in the study of the different species.

GENERAL NATURE OF SMUTS.

General Structure. For the information of those who are unacquainted with smuts, except in a very general way, it may be said that they are parasitic plants belonging to the group known as fungi. They can usually be easily told by the dusty outbreaks that they produce on certain parts of their hosts—the plants they attack—when they reach their reproductive stage. Examples familiar to everyone are such formations on corn and oats, known as corn smut and oat smut.

As with other fungi a smut fungus consists of two stages—the growth, or mycelial stage, and the reproductive, or spore stage. The former has to do with spreading the fungus through its host and gathering food for its development from the tissue through which it passes. The mycelium [Plate U] consists of hyaline branched threads, at first filled with protoplasmic contents, but with age losing this and becoming septate, that push their way between and into the cells of the host. Being within the plant, this stage is invisible to the naked eye, and there is usually nothing peculiar in the way of discolored or swollen tissue to separate such an infested plant from one free from the fungus.

The spore stage, however, [Plates A-Q] produced by large numbers of modified threads of the mycelium, being formed near the surface of some part of the plant, usually becomes visible from the first by the distortion thus produced and by the prevention of the normal growth of plant tissues or organs. These outbreaks mature into a dark, dusty mass of spores [Plate R, 1-6] which, in the forms we have to consider, are microscopic, roundish, single cell bodies that consist of a more or less thickened, and very often spiny wall enclosing protoplasmic contents. The wall is more or less tinted and thus gives the dark color to the spores in mass.

The life cycle of the smut is something as follows: The spores germinate [Plates S-T] by sending out a slender hyaline germ thread, or pro-mycelium, which either has the power of penetrating by very narrow infection threads directly into the young, tender tissue of its host and there giving rise to the mycelium, or else this germ tube remains short and at the septa on its sides or on its end gives rise to slender, short, colorless bodies, called sporidia, which under certain conditions of moisture and nourishment reproduce themselves in countless numbers by budding at their ends. In this way the number of germs is greatly increased and the chance of infecting the host likewise strengthened, since these sporidia in ordinary water may give rise by germination to slender infection threads whose office is the same as those originating from the germ-tube of the spore.

The smut germs can infect only their host plants, and these only when the exposed parts are quite young and usually only at certain particular places. Most frequently it is through the very young parts of the germinating seed that the fungus makes its entrance into its host, and then by the growth of its mycelium follows the upward growth of the plant, becoming visible finally through the formation of its spores, which in such cases are generally produced in those parts that would have given rise to the flowers.

Kinds. Such in general is the life history of these parasites. There have been found in Illinois about fifty different kinds occurring on some seventy-five different hosts. The forms considered in this paper are of especial interest because the hosts they inhabit are of economic importance.

Perhaps the most important ones are those that appear in the panicles of oats, known as loose and hidden smuts of oats,—so called because the former entirely, while the latter only partially, destroys the flower parts, the outer glumes at least in the latter case remaining more or less intact. Tall oat grass is also the host of a form similar in appearance to the hidden smut of oats, while loose smut of wheat is very much like that of the loose oat smut. Besides the loose smut, wheat is the host here of at least one, and, perhaps, both of the stinking smuts—

forms which occur in the grain without affecting the surrounding glumes, hence very easily overlooked. Corn smut, next to oat smut, is our most common species and is also the most conspicuous form, breaking out on almost any part of its host. This same smut also has been found at the Experiment Station on teosinte, a plant not ordinarily cultivated so far north. Barley is not now extensively raised in this state, and consequently the loose and covered smuts which destroy its spikes are not so common or important as they would be otherwise. The smut which destroys the seed of sorghum and broom-corn, known as grain smut, is sometimes a quite common and injurious foe of these plants though they are not widely cultivated. Head smut of sorghum, which differs greatly from the grain smut of the same host by changing the whole panicle into a large smutty mass, has been found here but once. The smut of grasses, which breaks out in rather inconspicuous dusty lines on the leaves, has for its hosts of economic importance timothy, redtop, and blue-grass, and is not uncommon, and occasionally is a quite injurious fungus. The smut which occurs in the spikes of Hungarian grass has been collected but once, and then in southern Illinois.

Damage done. The financial loss caused by any fungus depends upon several things, as follows: the value of the host as an economic plant, the part of the host most directly injured, the severity of the attack, and the frequency of occurrence. From a consideration of these points, if he has accurate data, one can get a fairly good idea of the loss caused by any fungus.

From the fact that the smuts very often destroy entirely the part of the plant for which it is raised, it is easier to make an estimate of the damage caused by them than in the case of most other fungi. For instance, if one finds that ten out of every hundred of his oat panicles are smuttled, he can make an estimate of 10 per cent. damage. It may be even more than this, for we know that in some plants the smut may gain entrance into the stalks but not succeed in producing its spores because of the too rapid growth or maturing of plant tissues. In this case the fungus presumably has an effect in reducing the quality and yield of seed, though it is not very likely that many plants are so infected or influenced enough to have a very appreciable effect.

A good many estimates have been made for various states and the country at large of the damage caused by different smuts, and these usually show the loss to be very considerable. In fact the smuts cause a greater loss among our strictly agricultural plants than any other fungi, unless it be the rusts. There is reason to suppose, however, that while these estimates may not in many cases be exaggerated, still they have been chiefly in the nature of guesses made for large areas based upon limited observation in some restricted area. Examinations made in various parts of this state have shown that while one can determine

quite accurately the loss caused by oat smut in any field, by making counts of several hundred heads in each of three or four places in it. still conclusions are not to be drawn from that field as to the amount of smut in other fields in the neighborhood. Neither, if he has gone over the fields of the neighborhood, is he justified in drawing conclusions from this as to the amount of smut in the rest of the state, at least not without some general inspection of it.

Of all the smuts in this state those of oats undoubtedly cause the greatest loss year after year. This is due to the facts that oats are very extensively raised, that the smut is found more or less abundant in all the fields (sometimes destroying as high as twenty to forty per cent.), and that the grain is directly and entirely destroyed. If wheat had not been disappearing somewhat from culture, it is very likely that the loose smut of this plant would cause a greater loss than the oat smuts, because, while it does not generally give so high a per cent. of smut, the value of the crop would more than offset this. Stinking smut of wheat in some localities or fields does considerable damage, but it has not such a universal occurrence as the loose smut. The smut on corn is one of the most common of these pests, but the loss caused by it is usually indirect; that is, the smut commonly breaks out on other parts of the plant than the ears and in such cases affects them only by using food that might go for their growth. The loss, however, is always something and in some fields undoubtedly becomes quite considerable, though it is doubtful if it causes as much damage as is generally supposed. The loss caused by the other smuts is more insignificant, due in part to the more restricted cultivation of the hosts and in part to a greater variability in the presence of the smuts that attack them. In occasional fields, however, they sometimes do much mischief.

PREVENTION OF SMUTS.

Theory. The fact that smuts cause so great a loss to certain of our agricultural plants early led to experiments to prevent their ravages. These attempts while mostly crude and ineffectual were still along the right line, in that they dealt with treatment of the seed. Smuts, with a few exceptions, unlike most other fungi, do not spread the disease from one plant to another. They are also more restricted as to the time and place of entrance to their hosts. With most of those of economic importance, corn smut being the prominent exception, infection is successful only when the germ threads can penetrate the very young tissue of the germinating seed. This being the case there is but a very short time, while the plant is still underground, that there is danger from the smut germs.

With most of the smuts the germs are not so generally distributed in the ground as to be a source of infection. It has been found that it

is those which adhere to the seed that are dangerous. These spores were blown on the seed in the field; or, in cases where there were smutty kernels, these became ruptured with the handling of the grain and thus distributed their spores to the seed. From these considerations it will be seen that the proper way to prevent the appearance of smut in a crop is to use seed that is free from living smut germs.

Use of clean Seed. One way to prevent smut would undoubtedly be the use of seed entirely free from germs. This is best accomplished by obtaining seed from fields that have had no smut in them, though it is much more difficult to do this with some crops than with others. If more attention, however, were paid to the source of seed, the losses caused by these fungi would be greatly diminished. One must not judge of the cleanliness of seed by a mere examination of it; since, except in those cases where the smut is present in smutty kernels, this would not show whether any germs were present or not. It takes a thorough knowledge of the field from which the grain came, and in some cases possibly its after handling, to determine the condition of the seed in this respect.

With such crops as oats, even when a person has used ordinary care in the selection of his seed, he may get varying results with different seasons. In most fields there is at least a little smut present, and the conditions of moisture, etc., especially at the time of planting, have much to do with determining whether this shall become greater in the succeeding crop. So it may happen that a farmer who one year has used care in the selection of seed gets a smuttier crop than he did some other year when he had not used this care. From such experience some farmers judge that season is the one influence that regulates the amount of smut. It is an important factor, but the most important factor is the degree of freedom of seed from germs.

The effect of neglect in selecting seed was shown in the investigations of amount of smut in this state. From complaints it was found on examination that the farmers of southern Illinois suffered much more from oat smut than those of central Illinois. In the former region much less attention had been paid to the seed used. That greater care in this direction would have been helpful was shown in the cases of a few persons who watched the condition of their oats.

Use of chemically treated Seed. Another way to prevent smut is to kill all of the germs that are attached to the seed. Experiments in soaking the seed with chemicals of various kinds have been tried for years in Europe and more recently in this country. Among the earlier things used were brine, lye, and copper sulfate. Most of the treatments seem to have been for the prevention of the stinking smut of wheat. With the exception of copper sulfate these earlier remedies have given little satisfaction, and, even with this, although to-day it is perhaps more

generally used over the world than any other treatment, there is considerable danger of injuring the seed when it is made severe enough to be quite efficient.

With the advent of experiment stations, more careful experimentation with a great variety of chemicals was conducted. From among the many tried there have been discovered several that give rather satisfactory results. New methods of treating the seed have also been developed. Formerly the seed was allowed to soak from one to twenty-four hours according to the strength of the solution. Now sprinkling the solutions over the grain, stirring the latter to wet it uniformly, seems to give as good results, while the work is much quicker and less cumbersome and the grain more easily dried. Of all the chemical solutions that have been tried, corrosive sublimate, potassium sulfid, Ceres pulver (apparently composed chiefly of potassium sulfid), copper sulfate, lysol, and formalin have given the best results.

Formalin which, without doubt, heads this list, is a commercial name for a forty per cent. solution of formaldehyde. While not poisonous it has a very pungent and penetrating odor, making it one of the best disinfectants. With seed treatment for smuts, it is used at the rate of one pound of the liquid to forty or fifty gallons of water. It is sprinkled on the grain, while the latter is thoroughly stirred, at the rate of one to two gallons a bushel. After treatment the grain is left in sacks for a few hours and then planted. The simplicity of this treatment, with possibilities of its further improvement, will undoubtedly make it more popular than the following very effective though somewhat cumbersome method.

Use of hot Water treated Seed. Jensen, of Denmark, was the first person to bring into prominence the use of hot water as a seed treatment. The Kansas Experiment Station in this country, stimulated by these results, also made numerous experiments with it for smuts of oats and wheat, and since then other stations have contributed experiments, so that the literature on this method of treatment is perhaps more extensive than that of all the other treatments combined. Hot water treatment of seed is without doubt the most generally effective treatment that has been discovered. The objections against it are its cumbersomeness, the work required to treat large amounts of seed, and the difficulty in drying the seed after treatment. These are objections that hold least with the formalin treatment just described, though even with this, as now conducted, the wetness of the seed is objectionable.

This treatment consists in the immersion of seed in hot water, the time of immersion and temperature of the water varying with the seed to be treated. In general the immersion varies from five to fifteen minutes and the temperature (inversely to the time) from 130° to 145°F. It is best not to treat over a bushel at a time, in order that all of the

grain may receive equal exposure to the heat. It has been found desirable to have two barrels of hot water, one at the required temperature and the other a little below it, so that the seed being placed in the latter barrel first has its temperature raised enough to prevent it lowering that of the second, which must be kept at the required degree. A coarse gunny-sack to hold the seed, with plenty of room for circulation of the water, a cross-bar and a lever to lift the sack in and out of the barrels, means for heating plenty of water, and a trustworthy thermometer are essentials for this treatment.

One man is needed to keep track of the time of immersion and temperature of water, and another to dip the seed. When placed in either barrel the sack should be raised clear of the water several times to allow it to drain off or else the temperature of the seed will never come up to that of the water. A minute or two is all that is necessary for treatment in the first barrel and then the sack is quickly transferred to the second and after several dippings kept entirely immersed for the remainder of the required time. After treatment the seed is immediately spread out to cool and if not planted soon must be turned over every day until thoroughly dry.

It seems desirable to treat seed about the time it is to be planted, for otherwise it takes considerable space and care to dry thoroughly any quantity and there is danger of its germinating somewhat before this is accomplished. If sown broadcast by hand it can just as well be sown as soon as treated, but if planted by drill it should be dried somewhat and even then it will not feed well, unless a force drill is used. In either case the swollen condition of the grain should be taken into consideration and allowance made for the desired rate per acre. Generally hot-water treated seed germinates quicker and obtains an earlier start than untreated seed.

For the benefit of those who may wish to use any of these seed treatments, there is given in Table 1 general directions for the most successful methods with the various smuts of our cereals. The directions printed in italics are those recommended, having been found most efficient in our experimental work.

TABLE I. MOST SUCCESSFUL TREATMENTS FOR PREVENTION OF SMUTS.

Kind of smut.	Hot water treatment.	Formalin treatment.	Potassium sulfid treatment.	Copper sulfate treatment.
Loose and hidden smuts of oats.	*Soak seed 10 minutes in water at 132°–3° F.*	*Sprinkle seed thoroughly with formalin (1 lb. to 40 or 50 gals. water), leaving in piles for several hours.*	Sprinkle seed thoroughly with potassium sulfid (1 lb. to 10 gallons water).	Sprinkle seed thoroughly with copper sulfate (1 lb. to 10 gallons water).
Stinking smut of wheat.	*Same as with oats, or treat for 5 minutes at 134°–6° F.*	*Same as for oats.*	Smutted kernels may be removed by immersing seed in water and after thoroughly stirring skimming off the floating grain. This does not take the place of seed treatment but may serve to make it more efficient.	Sprinkle seed thoroughly with copper sulfate (1 lb. to 5 or 10 gals. water). With stronger rate use lime afterward.
Grain smut of sorghum and broom-corn.	*Soak seed 15 minutes in water at 135° F.*	Sprinkling methods more or less efficient when used stronger. See experiments.		
Loose smut of wheat.	Soak seed four hours in cold water; let seed stand four more hours damp in sacks; then treat with hot water 133° F. for 5 minutes. This treatment is severe enough to kill part of the seed, so use larger amount per acre. Also it is perhaps best to treat only enough to obtain free seed for another year's use.			
Loose and covered smuts of barley.	Soak seed as with loose smut of wheat, but treat with hot water at only 128°–30° F. for 5 minutes. Use extra amount of seed per acre and best treat only enough for next year's seed. The covered form is prevented by the ordinary form of hot water treatment.			
Common smut of Indian corn.	Seed treatments for prevention of corn smut have been found to be useless, as the smut gains entrance through the very young aerial parts. Care in selecting a hardy variety and in avoiding use of manure that year on the land or in using land that the previous year produced a smutty crop should manifest itself, however, in a minimum amount of smut.			
Smut of oat grass, head smut of sorghum, grain smut of Hungarian grass, and leaf smut of grasses.	So far as found methods for the prevention of these smuts have not been tried to any extent. Bolley of North Dakota recommends the same treatments for Hungarian grass smut as for oats, and these treatments would probably prove efficient in most of the other cases.			

LOOSE AND HIDDEN SMUTS OF OATS.

Ustilago Avenæ (Pers.) Jens. *Ustilago levis* (Kell. & Sw.) Magn.

Life History. There are two distinct smuts* of oats. In the loose smut the infected flowers of the panicle are entirely destroyed by the spore formation, and each is changed into a dusty olive brown mass that after maturity is gradually disseminated, eventually leaving behind only the naked branches of the panicle. With the covered smut the destruction of the flower parts is much less complete, the spore mass is less dusty and more of a blackish brown. In this form the smut usually shows through the thin covering membrane at base of the flower, the upper part of the glumes remaining intact. More rarely the glumes show no sign of the smut which is limited to the parts within, and even sometimes the hard flowering glume and palet are normally developed as if enclosing a sound seed, and the presence of the fungus is determined only by tearing these apart. These enveloping parts furnish such protection against dissemination of the spores that frequently the smutted flowers may be found in badly smutted grain after it is threshed. In one instance only was the smut found developing in any other part of the plant, the exception being in an upper leaf where it broke out in rather inconspicuous lines. In both species there are occasionally found panicles in which the lower flowers only are smutted, and all or a part only of the culms from a stool may show the presence of the fungus. Besides destroying the grain these smuts more or less stunt the growth of the culms so that they average several inches shorter than the free.

The spores of the two species also present but small differences. Those of *Ustilago Avenæ* are minutely echinulate, lighter colored on one side, and vary chiefly from elliptical to spherical (usually subspherical) in shape and from 6-9*u*† in diameter. With *Ustilago levis* the difference consists in a smooth membrane, with perhaps spores somewhat darker in color and more uniform in shape and size. Both germinate readily in water, though the hidden smut apparently the more abundantly. A three- or four-celled pro-mycelium is produced from the lighter side of the spore and this gives rise to a few sporidia at the

*For a long time the writer considered that *Ustilago Avenæ* var. *levis* Kell. & Sw. (later raised to specific rank by Magnus as *Ustilago levis*) was only *Ustilago Avenæ* in which the fungus had been tardy in gaining entrance into the floral parts and so being only partially effective in destroying them. Lately, however, going carefully over all the herbarium collections and taking into consideration field observations, it seems more probable that this host really has two distinct species. Our experiments were made under the former impression and so no special attention was paid at the time to the character of the infested panicles. It is undoubtedly true, however, that with our prevention and infection experiments we were working largely, if not entirely, with the covered smut, *Ustilago levis*.

†A *u* is one twenty-five thousandth of an inch.

sides or apex, or often to germ threads either by prolongation of the pro-mycelium or by development of basal branches. These probably act as infection threads. Knee joints, formed by bending of the thread closely on itself or by lateral outgrowths around the septum, also occur. The sporidia develop infection threads. The pro-mycelium sometimes becomes abstricted near the base and falls off, continuing its development alone. In nutrient solutions the germination is more vigorous, though not always more abundant, and the sporidia are much more common, because of their reproduction by budding, until exhaustion of nutrient, when they may produce infection threads.

It has been proved by seed treatment that infection takes place from the spores attached to the seed. Our experiments* with covered smut also show, as claimed by Jensen, that it is those spores which in the field have succeeded in falling down between the flowering glumes while open during shedding of pollen that are most responsible. The glumes are thus a great means of protection after they have once closed around the seed. Infection takes place by the penetration of the infection threads of the pro-mycelia or of the sporidia into the very young tissue of the germ, usually before or soon after protruding from the enveloping glumes. Once having gained entrance the fungous threads must succeed in reaching the young tissue just beneath the growing point, after which they follow the upward growth during the several weeks necessary for the development of the oats, showing no external sign of the smut's presence until the protruding of the panicle. When the flower parts are being differentiated the fungus for the first time seems to gain supremacy and its reproductive stage is now developed to the destruction or prevention of these parts, so that by the time the panicles appear the spores are mostly developed.

Damage. As has been pointed out the oat smuts by producing their spores in the panicles prevent seed formation, and usually destroy all of the grain of such a panicle. The loss, then, is easy of estimation after one has determined the per cent. of smutty panicles in a field. In order to get as accurate an idea as possible of the damage caused by these smuts, since they inflict a greater loss than any of the others, a large number of determinations of the per cent. of smut in oat fields has been made. The data thus obtained are given in Table 2. Most of these determinations were made in Champaign county and on two bicycle trips taken in 1897-8 through central and southern Illinois. In these cases nearly every field seen along the road was entered and a determination made. A few counts were made by persons interested in various parts of the state, and the numbers 163-195 are total counts of

*Smut mixed dry with oats gave only 2% smutted plants, that mixed wet gave 9%, while hulled seed mixed wet gave 71%. See Table 7.

small plats raised at the Experiment Station from seed obtained from thirty-four localities scattered over the state. It was found that a quite accurate determination could be made by counting from five hundred to a thousand panicles in each of three or four places scattered over the field, noting the number of smutty panicles in the total counts. From these observations and from correspondence carried on concerning this subject, the following conclusions are made.

Taking the state as a whole the damage done varies with different years, in some being quite considerable and in others rather inconspicuous. The years 1895-7 were ones in which the loss was considerably higher than in 1898-9, perhaps the greatest extremes being presented by the years 1896 and 1898. This variation is probably largely due to seasonal variations.

There is a difference in different parts of the state as to the comparative loss from this fungus. For instance, the hard pan region of southern Illinois, the northern boundary of which is somewhere near the regions of Pana and Mattoon, undoubtedly has suffered more in this respect than the more fertile part of central Illinois, of which Champaign county may be taken as a type. This was plainly brought out by correspondence and by the observations made on the bicycle trip in 1897 which covered a considerable territory in both of these regions, the general average of counts made showing 11% of smut in one case and 3% in the other. This difference is attributable to the difference in seasons of the two places, the character of the soils (which are entirely different) as affecting retention of water, and the care used in the selection of seed. These conditions are apparently all more favorable for the development of smut in the former region.

In the same locality there may be a considerable variation from year to year. For example, in the hard pan district, the counts in 1897 showed an average loss of 11%, while the next year this dropped down to 4%. As explained before these differences are largely due to seasonal variations.

In the same locality there may be quite a wide variation between different fields, as is shown by an inspection of the figures given in the table. While the character of the seed used may explain in part this difference, still some of it is due to difference in time and manner of planting, moisture, the soil, etc.

The average of the counts made in all parts of the state is 6%. This is probably a little higher, rather than lower, than the actual loss year after year, as but few counts were made in northern Illinois, which is more like the central than the southern part of the state in this respect. This per cent. is a little lower than is usually made for other states. The average yearly value of the oat crop in this state for 1895–1898, as taken from the reports of the U. S. Dept. of Agr. was about $15,500,000. If

TABLE 2. PER CENT. OF SMUT IN ILLINOIS OAT FIELDS, 1892-1898.

No.	Date.	Locality.	Total counts.	No. smutty.	% smutty.
1	1892	Urbana Experiment Station	700	11	2
2	"	" " "			½
3	"	" " "			5
4	"	" " "			2
5	"	" " "			2
6	"	" " "			2
7	"	" " "			0
8	"	" " "			0
9	"	" " "			0
10	"	" " "	800	107	13
11	1895	" " "	1000	20	2
12	"	" " "	1000	40	4
13	"	" " "	1100	18	2
14	"	" " "	900	10	1
15	"	" " "	1500	7	½
16	"	" " "	1500	22	1
17	"	" " "		0	0
18	"	" " "			1
19	1896	Polo (Yeakel)	535	12	2
20	"	" "	652	18	3
21	"	" "	391	29	7
22	"	" "	593	123	21
23	"	Odin (Vaughn)	1203	252	21
24	"	Farina (McCluer)	1287	216	17
25	"	" "	1477	414	28
26	"	Taylorville (Shamel)	1670	342	20
27	"	" "	1422	316	22
28	"	Edgewood (Bartley)	1030	310	30
29	"	" "	1590	299	19
30	"	Champaign County	1700	347	20
31	"	" "	4000	86	2
32	"	" "	4200	299	7
33	"	" "	4000	317	8
34	"	" "	3000	108	4
35	"	" "	3000	71	2
36	"	" "	3000	385	13
37	"	" "			3
38	"	" "			5
39	"	" "			5
40	"	" "			5
41	"	" "			5
42	"	" "			1
43	"	" "			3
44	"	" "			2
45	"	" "			3
46	"	" "			10
47	"	" "			5
48	"	" "			7
49	"	" "			8
50	"	" "			5
51	"	" "			4
52	"	" "			1
53	"	" "	3000	439	15
54	"	" "			5
55	"	" "			8
56	"	" "			2
57	"	" "			1
58	"	" "			1
59	"	" "			3
60	"	" "			1
61	"	" "			1

TABLE 2. PER CENT. OF SMUT IN ILLINOIS OAT FIELDS, 1892-98.—*Continued.*

No.	Date.	Locality.	Total counts.	No. smutty.	% smutty.
62	1896	Champaign County	.....	.....	10
63	1897	Urbana to Tuscola	2500	37	1
64	"	" "	2000	30	2
65	"	" "	2000	48	2
66	"	" "	2000	55	3
67	"	" "	2500	20	1
68	"	" "	2000	7	½
69	"	" "	2000	223	11
70	"	" "	2000	179	9
71	"	" "	1000	103	10
72	"	" "	2000	97	5
73	"	" "	2000	26	1
74	"	Neoga to Sigel	2000	315	16
75	"	" "	2000	401	20
76	"	" "	2000	239	12
77	"	" "	2000	190	10
78	"	" "	2000	82	4
79	"	" "	2000	37	2
80	"	" "	2000	75	4
81	"	Sigel to Effingham	2000	500	25
82	"	" "	1000	238	24
83	"	" "	2000	264	13
84	"	" "	2000	382	19
85	"	" "	2000	246	12
86	"	" "	2000	239	12
87	"	" "	1000	68	7
88	"	" "	1500	190	13
89	"	" "	2000	144	7
90	"	" "	1000	152	15
91	"	" "	1000	109	11
92	"	" "	1000	96	10
93	"	Effingham to Vandalia	1800	348	19
94	"	" "	1600	33	2
95	"	" "	1600	125	8
96	"	" "	1700	94	6
97	"	" "	1600	182	11
98	"	" "	1600	179	11
99	"	" "	1600	102	6
100	"	" "	1600	237	15
101	"	" "	1600	8	½
102	"	" "	1600	307	19
103	"	" "	1600	389	24
104	"	" "	1600	435	27
105	"	" "	1600	259	16
106	"	" "	1600	255	16
107	"	" "	1600	232	15
108	"	" "	1600	164	10
109	"	" "	1600	118	7
110	"	" "	1600	187	12
111	"	" "	1600	39	2
112	"	" "	1600	245	15
113	"	Vandalia to Pana	1200	120	10
114	"	" "	1700	214	13
115	"	" "	1600	123	8
116	"	" "	1600	128	8
117	"	" "	1600	145	9
118	"	" "	1600	253	16
119	"	" "	1600	55	3
120	"	" "	1600	97	6
121	"	" "	1600	80	5
122	"	" "	1600	183	11

TABLE 2. PER CENT. OF SMUT IN ILLINOIS OAT FIELDS, 1892–1898.—*Continued.*

No.	Date.	Locality.	Total counts.	No. smutty.	% smutty.
123	1897	Vandalia to Pana	1600	224	14
124	"	" "	1600	150	9
125	"	" "	1600	365	23
126	"	" "	1600	222	14
127	"	" "	1600	290	18
128	"	" "	1600	196	12
129	"	" "	1600	85	5
130	"	" "	1600	34	2
131	"	" "	1600	117	7
132	"	" "	1600	60	4
133	"	Pana to Decatur	1600	77	5
134	"	" "	1600	146	9
135	"	" "	1600	192	12
136	"	" "	1600	321	20
137	"	" "	1600	51	3
138	"	" "	1600	50	3
139	"	" "	1600	180	11
140	"	" "	1600	455	28
141	"	" "	1600	46	3
142	"	" "	1600	379	24
143	"	" "	1600	257	16
144	"	" "	1600	90	6
145	"	" "	1600	476	30
146	"	" "	1600	68	4
147	"	" "	1600	132	8
148	"	Decatur to Cerro Gordo	1600	71	4
149	"	" "	1600	94	6
150	"	" "	1600	60	4
151	"	" "	1600	18	1
152	"	" "	1600	80	5
153	"	" "	1600	63	4
154	"	" "	1200	91	8
155	"	Champaign County	2000	40	2
156	"	" "	2000	8	½
157	"	" "	2000	16	1
158	"	" "	2000	65	3
159	"	" "	2000	40	2
160	"	" "	1000	12	1
161	"	" "	1200	5	⅓
162	"	" "	1200	26	2
163	"	New Windsor	1154	20	2
164	"	Elva	778	44	6
165	"	Geneseo	877	3	⅓
166	"	Norwood	521	13	2
167	"	Melville	1046	38	4
168	"	Delavan	1306	16	1
169	"	Oneida	839	8	1
170	"	Elva	713	27	4
171	"	Womac	1066	5	½
172	"	Macon	1144	32	3
173	"	Malta	803	19	2
174	"	Washburn	1217	39	3
175	"	Decatur	859	42	5
176	"	Argenta	883	10	1
177	"	Sycamore	908	14	2
178	"	Pana	1033	70	7
179	"	Beecher	789	31	4
180	"	Jerseyville	1111	61	5
181	"	Clear Creek	1225	22	2
182	"	Wasco	900	14	2
183	"	Taylorville	1172	20	2

TABLE 2. PER CENT OF SMUT IN ILLINOIS OAT FIELDS, 1892–1898.—*Continued.*

No.	Date.	Locality.	Total counts.	No. Smutty.	% Smutty.
184	1897	Elmwood	995	9	1
185	"	Mt. Carroll	794	1	1/8
186	"	Bishop	826	4	1/2
187	"	Polo	1474	18	1
188	"	Richview	840	17	2
189	"	Panola	744	0	0
190	"	Canton	950	7	1
191	"	Plainfield	736	10	1
192	"	Bellville	1353	1	0+
193	"	Edgewood	1266	99	8
194	"	Melville	1258	4	1/3
195	"	Springfield	1013	49	5
196	"	Moweaqua	853	34	4
197	1898	Ashley to Irvington	2000	39	2
198	"	" "	1700	149	9
199	"	" "	1900	84	4
200	"	" "	1500	57	4
201	"	" "	2000	69	3
202	"	Centralia to Kinmundy	2000	36	2
203	"	" "	2000	21	1
204	"	" "	2000	116	6
205	"	" "	2000	61	3
206	"	" "	1500	2	1/8
207	"	" "	1700	105	6
208	"	" "	2000	55	3
209	"	" "	2000	82	4
210	"	" "	2000	42	2
211	"	" "	2000	14	1
212	"	" "	1900	113	6
213	"	" "	2000	105	5
214	"	" "	2000	41	2
215	"	" "	2000	52	3
216	"	" "	1500	26	2
217	"	" "	2000	139	7
218	"	Mason to Effingham	2000	156	8
219	"	" "	2000	44	2
220	"	" "	2000	171	9
221	"	" "	2000	80	4
222	"	" "	2000	40	2
223	"	" "	2000	46	2
224	"	" "	2000	97	5
225	"	" "	2000	66	3
226	"	" "	2000	68	3
227	"	" "	2000	115	6
228	"	" "	2000	71	4
229	"	" "	2000	89	4
230	"	" "	2000	59	3
231	"	" "	2000	131	7
232	"	" "	2000	87	4
233	"	" "	2000	114	6
234	"	" "	2000	86	4
235	"	" "	2000	155	8
236	"	" "	2000	82	4
237	"	Champaign County	2000	1	0+
238	"	" "	2000	36	2
239	"	" "	2000	73	4
240	"	" "	2000	54	3
241	"	" "	2000	77	4
242	"	" "	2000	88	4
243	"	" "	2000	44	2
244	"	" "	2000	68	3

TABLE 2. PER CENT. OF SMUT IN ILLINOIS OAT FIELDS, 1892–1898.—*Continued.*

No.	Date.	Locality.	Total counts.	No. smutty.	% smutty.
245	1898	Champaign County.	2000	42	2
246	"	" "	2000	66	3
247	"	" "	2000	102	5
248	"	" "	2000	26	1
249	"	" "	2000	66	3
250	"	" "	2000	84	4
251	"	" "	2000	78	4
252	"	" "	2000	3	½
253	"	" "	2000	17	1
254	"	" "	2000	22	1
255	"	" "	2000	9	½
256	"	" "	2000	5	¼
257	"	" "	2000	13	1
258	"	" "	2000	7	⅓
259	"	" "	2000	16	1
260	"	" "	2000	13	1
261	"	" "	2000	32	2
262	"	" "	2000	3	½
263	"	" "	2000	0	0
264	"	" "	2000	22	1
265	"	" "	2000	12	1
266	"	" "	2000	40	2

6% represents the average loss it would mean that this fungus cost the farmers of this state during that time about a million dollars a year.

The injurious effect of smut upon this host is shown by the weights and measures given in Table 3. These were taken from all of the oats grown on two small plats under similar conditions, except that one plat was considerably more than half smutted, while the other was practically free. The figures show that the loss of grain may be partial or entire for an infected plant (all the culms from one stool), in this case the wholly smutted plants greatly outnumbering those only partially smutted;

TABLE 3. EFFECT OF SMUT ON OATS.

Plat.	Plants.	Weight of entire plants.	Ratio weight per 100 culms	Weight of grain.	Ratio weight per 100 culms.	No. plants	No. culms	Average No. culms per plant	Average length of culms.
Very smutty plat of oats.	Smut free.	21½ oz	12	5 oz.	3	41	179	4.4	49 in.
	Partially smutted	7½ oz.	8	1 oz.	1	16	90	5.6	*44 in.
	Wholly smutted.	26 oz.	7	0 oz.	0	99	358	3.6	40 in.
Practically free from smut.	Smut free.	59 oz.	13	15¼ oz.	3	110	462	4.2	48 in.
	Wholly smutted	¾ oz.	9	0	0	2	8	4.	45 in.
	Partially smutted.	No plants.							

*Average length smutted 40, of free 48 inches.

that the weight of smutted culms is less than that of the free, while their length is reduced on the average several inches. There is some ques-

tion as to its effect on the stooling habit, since the average number of culms per plant for those entirely smutted was less than for those entirely free, while the partially smutted averaged higher than either.

EXPERIMENTS.

Miscellaneous Experiments. As is shown in Table 2 there may be a considerable variation in the amount of smut in different fields in the same locality. Undoubtedly this is not due entirely to the character of the seed sown, since in some known cases where the same seed has been used such differences have still appeared. It was to study these variations, and determine as far as possible their causes, that in 1897-8 a number of different experiments were conducted.

TABLE 4. RELATION OF TIME OF PLANTING OATS TO % OF SMUT. – 1897.

Ordinary seed.		Row 1.			Row 2.			Row 3.			Aver.
Plat.	Date of planting.	Total counts	No. smutty	% smutty	Total counts	No. smutty	% smutty	Total counts	No. smutty	% smutty	% smutty
1	March 22	850	12	1	910	7	1	742	7	1	1
2	" 29	384	13	3	639	8	1	864	31	4	3
3	April 5	656	4	1	590	11	2	654	20	3	2
4	" 13	592	6	1	609	8	1	611	25	4	2
5	" 19	539	19	4	646	19	3	645	15	2	3
6	" 26	195	0	0	696	5	1	684	8	1	⅔
7	May 4	513	10	2	502	12	2	617	22	4	3
8	" 10	353	17	5	448	1	¼	515	7	1	2
9	" 17	447	14	3	533	13	2	654	11	2	2
10	" 24	151	2	⅔	135	0	0	65	0	0	⅓
Very smutty seed											
1	April 5	874	92	11	898	106	12	807	120	15	13
2	" 13	798	138	17	792	107	14	1062	172	16	16
3	" 19	860	117	14	939	111	12	940	100	11	12
4	" 26	658	38	6	700	101	14	807	81	10	10
5	May 4	633	76	12	659	104	16	800	105	13	14
6	" 10	507	21	4	622	34	5	640	64	10	6
7	" 17	400	40	10	597	64	11	807	115	14	12
8	" 24	334	29	9	330	23	7	443	48	11	9
9	" 31	197	9	5	275	16	6	270	14	5	5

One of the most extensive of these experiments was the planting of the same seed oats at different dates to determine if time of planting had an influence on amount of smut. In 1897 two lots of oats, one of quite smutty and the other of supposedly rather clean seed, were sown each week for a series of ten weeks. Care was used to plant the seed as nearly as possible alike each time and each planting was made in three rows—the per cent. of smut being determined for each as well as their average—to serve as checks on each other. While there was some variation between the different weeks (Table 4) it was not always uniformly marked in the three rows, except in the case of the seed planted very late, May 24th and after, in which cases the smut was undoubtedly decreased.

This same experiment was repeated again in 1898 (Table 6) when

only very smutted seed was used, as such variation would be most likely to manifest itself with this. The seed was planted in duplicates in three different ways for a series of eight weeks. It was again shown in every case that the very late plantings (on and after May 16th this year) had lowered the per cent. of smut. This year the first planting seemed to have been similarly affected. The variations between the plantings made within the proper season were like those of the preceding year; that is, not so marked and uniform, but doubtless due in part to the difference in time of planting.

This effect of late planting was also noticed in other experiments carried on in 1898. The same seed planted in season gave 6-10% smut, while that planted far out of season had this reduced to less than 2%. In the examination of fields just before harvest it has also been noticed that those that were yet far from being ripe, indicating an unusually late planting, gave the lowest per cents. of smut. It is also claimed by some farmers that where "freezing in" the seed is practiced there is less smut than when the same seed is sown later.

The proper explanation of this reduction in per cent. of smut in oats planted out of season seems to be, in part, that fewer plants are originally infected, because the amount of moisture at the time of later plantings is not so great and in the earlier ones the heat conditions are not so favorable, but also, in part, to the fact that oats planted out of season have very unfavorable conditions for growth and those that have both the smut and these to combat would be most likely to succumb.

In 1897-8 experiments were also carried on to determine if manner of planting affected the per cent. of smut. The experiments of 1897 (consisting of planting seed one, two, four and six inches deep, see Table 5) were not very extensive and did not show any marked difference in per cent. of smut.

The more extensive experiments of 1898, however, gave some very interesting results that can only be attributed to the manner of sowing

TABLE 5. RELATION OF DEPTH OF PLANTING OATS TO % OF SMUT. 1897.

Plat.	Counts.	One inch deep.			Two inches deep.			Four inches deep.			Six inches deep.
		Row 1	Row 2	Average.	Row 1	Row 2	Average.	Row 1	Row 2	Average.	
Ordinary seed.	Total counts....	590	579	.....	449	515	.....	492	541	.....	191
	Number smutty.	32	42	.....	20	22	.....	21	32	.....	16
	Per cent. smutty	5	7	6	4	4	4	4	6	5	8
Smutty seed.	Total counts ...	634	612	.....	582	728	.....	329	272	.....	51
	Number smutty.	111	71	.....	67	84	.....	49	37	.....	7
	Per cent. smutty	18	12	15	12	12	12	15	14	14	14

the seed, since the experiments were carried on in duplicate through a series of eight weeks and uniformly gave the same result till lateness of planting blotted out the differences. This year the seed was sown in

TABLE 6. RELATION OF TIME AND MANNER OF PLANTING OATS TO % OF SMUT. 1898.

No.	Time of planting.	Counts.	Broadcast.			One inch deep.				Four inches deep.		
			1st.	2d.	Av. %	1 Row.	2 Row.	3 Row.	Av. %	1 Row.	2 Row.	Av. %
1	April 4.	Total.....		3275		835	600	550		440	600	
		Smutty.....		42		17	22	23		38	41	
		% smutty ...		1.3	1.3	2.	3.7	4.2	3.3	8.7	6.8	7.7
2	April 12.	Total.....	1850	2220		655	580	800		700	700	
		Smutty.....	49	112		58	37	49		42	68	
		% smutty....	2.6	5	3.8	8.9	6.4	6.1	7.1	6	9.7	7.8
3	April 18.	Total.....	1580	3300		745	700	800		900		
		Smutty.....	43	66		50	59	72		133		
		% smutty....	2.7	2	2.3	6.7	8.4	9	8.0	14.8	.....	14.8
4	April 25.	Total.....	1800	1650		900	800	950		485	800	
		Smutty.....	33	28		74	71	68		54	109	
		% smutty....	1.8	1.7	1.7	8.2	8.9	7.2	8.1	11.1	13.6	12.5
5	May 2.	Total.....	1350	2190		700	700	700		325	380	
		Smutty.....	31	60		70	65	60		52	71	
		% smutty....	2.3	2.7	2.5	10	9.3	8.6	9.3	16	18.7	17.8
6	May 9.	Total.....	*1100	2490		700	870	800		645	952	
		Smutty.....	8	87		63	66	67		98	171	
		% smutty....	0.7	3.5	2.1	9	7.5	8.4	8.3	15.2	18.	16.6
7	May 16.	Total.....	775	1731		532	562	663		446	663	
		Smutty.....	7	23		24	11	29		25	38	
		% smutty....	0.9	1.3	1.1	4.5	2	4.3	3.6	5.6	5.7	5.7
8	*May 23.	Total.....		444		438	343	340		164	150	
		Smutty.....		2		9	2	8		0	3	
		% smutty....		0.4	0.4	2	0.6	2.3	1.6	0	2	1.0

*Came up very poorly.

three different ways: namely, broadcast, lightly covering by raking over the ground; in rows one inch deep; and in rows four inches deep. Table 6 shows that uniformly the seed sown broadcast gave a low per cent. of smut, an average of 2%, that one inch deep a much higher per cent., averaging 6%, while that four inches deep gave a quite smutty crop, averaging 10%. The same seed, in a different experiment, sown broadcast and then harrowed in gave about the same per cent. as that planted one inch deep.

Such differences may be accounted for by the differences in amount of available moisture and the exposure of the seed germ. The seeds planted four inches deep had the most moisture and the germs were exposed through a greater length and for a longer time, as it took one or two days longer for them to appear above ground. On the other hand these conditions least obtained with the seed sown broadcast and scarcely covered.

While it is true that character of season and manner of planting may be factors in the determination of the per cent. of smut, the most important factor is the relation of the seed to the position and number of smut germs attached to it. The results given in Table 7 show some interesting data along these lines.

In the first place it is shown that it is the smut attached to the seed that causes infection, and not any that may be in the land or blown to the plant. Those plats that had the seed treated gave free crops, and those that had more or less living smut attached to seed gave a more or less smutty crop.

While numbers of spores present were significant their position seemed to be of more importance. The glumes are of great advantage in protecting the seed germ at the very first from all the smut germs on the outside. After the seed has matured it is not very easy for spores

TABLE 7. RELATION OF SMUT GERMS TO SEED IN INFECTION.

Plat.	Kind of treatment given the seed.	Total counts.	No. smutty.	% smutty
5	Hot water treated seed of 1897 treated again in 1898, 132° F. for 7 minutes	Practically free.		0
6	Same as 5 but not treated in 1898	Practically free.		0
7	Untreated seed of 1897 having 20 % smut	4000	76	2
8	Same as 7 but treated in 1898, 132° F. for 7 min.	Practically free.		0
9	Same as 6 but mixed wet with smut when planted	3400	322	9
10	Same as 6 but mixed dry with smut as soon as ripe	2500	50	2
11	Same as 6 but seeds hulled and mixed wet with smut just before planting	720	513	71
12	Same as 11, but seeds not mixed with smut	875	9	1

to be carried down between the tightly enveloping glumes. As has been claimed by other experimenters it is chiefly the smut that falls down

between the glumes when they are normally open in the field that causes the damage. Experiments in plats 9-11 well illustrate this. In plat 10 oat seed that was obtained from a field free from smut was abundantly mixed with dry spores as soon as gathered. This gave 2% of smut next year. The same kind of seed when mixed wet with spores just before planting (a treatment that would carry more of the spores inside the glumes than the dry mixing) gave 9% of smut. The seed, however, that had the glumes removed and was then mixed wet with smut gave 71%, a percentage rarely ever equalled. The lot hulled but not mixed with smut gave only 1%.

TABLE 8. TIME OF APPEARANCE OF OAT SMUT.

Plat.	June 21, '97.			June 30, '97.		
	Total culms.	No. smutty.	% smutty.	Total culms.	No. smutty.	% smutty.
1	390	19	5	874	92	11
2	525	26	5	898	106	12
3	290	4	2	807	120	15
4	286	6	2	798	138	17
5	254	6	2	792	107	14
6	299	10	3	1062	172	16
7	500	2	2/5	850	12	1
8	655	4	2/5	910	7	4/5
9	489	0	0	742	7	1
Average.....			2	Average.....		10
Plat.	June 18, '98.			July 8, '98.		
1	1700	13	4/5	3275	42	1
2	750	7	1	1850	49	3
3	200	2	1	1580	43	3
4	20	6	30	720	513	71
Average.....			8	Average.....		20

Table 8 gives the results of an experiment to determine time of appearance of the smutty panicles of oats. It is claimed by some that certain smuts hasten maturity of the plant, the smutty panicles being the first to appear. The examinations of the cases given here were made on two different dates, the first soon after the earliest panicles began to appear and the second after they were all out. The results show that with oats the influence of the smut is retarding rather than accelerating.

Prevention Experiments. The aim of the work in prevention of oat smut has been to determine the most efficient and at the same time the most practical of known remedies rather than to discover any new fungicide. The first experiments were made in 1895, at which time nothing had been done by the Station in this direction, although a good deal of successful experimentation had been made by some other stations. For the first two years only the hot water treatment was tried. The amounts of seed treated varied from a few quarts up to a bushel and a half. The treatments proved uniformly successful in practically preventing the smut. Details of the treatments and counts from treated and check plats are given in Table 9.

TABLE 9. RESULTS OF HOT WATER TREATMENT FOR OAT SMUT. 1895–6.

Plat.	Treatment given seed.	Smutty.	Total* counts.	% smutty.
I.	132°–135° F. for 15 minutes. 1 peck.....	2	28,341	0
II.	Check plat. Untreated	338	25,241	1.3
1	129°–130° F. for 10 minutes. 1 gallon.....	3	27,500	0
2	Check plat. Untreated.....	600	36,000	1.7
3	132°–133° F. for 10 minutes. 1 gallon.....	1	23,000	0
4	Check plat. Untreated.....	350	18,000	2
5	134°–136° F. for 15 minutes. 1 gallon.....	3	29,000	0
A	131° F. for 8 minutes. 1½ bushels	28	224,000	0
B	Check plat. Untreated.....	128	4,100	3
C	130°–155° F. for 8 minutes. 1½ bushels...	53	380,000	0
D	Check plat. Untreated..	378	6,700	5.6

*These are mostly estimated from counts of parts of the plats.

The results with hot water having been so satisfactory, as far as preventing smut, it was decided in the experiments conducted in 1897 to compare this treatment with the other most promising ones recommended by various experimenters with the hope of determining if it were the most practical as well as the most efficient method. In these experiments ten pounds of very smutty seed was treated in each case and then planted in one-fifth acre plats. (See Table 10). That treated by sprinkling was made very thorough. With the copper sulfate treatment half the seed was mixed with air slaked lime to help dry it and

TABLE 10. VARIOUS TREATMENTS FOR PREVENTION OF OAT SMUT. 1897.

Plat.	Treatment given seed.	Smutty.	Total counts.	% smutty.
1	Hot water, 134°–132° F. for 8 minutes.....	Found 20 in ⅛ acre	smutted plat.	0
2	Potassium sulfid, thoroughly sprinkling, rate of 1 lb. to 12 gals. water.....	113	3000	3.8
3	Ceres pulver, thoroughly sprinkling, rate of 1 lb. to 12 gals. water.....	74	3400	2.2
4	Copper sulfate, thoroughly sprinkling, rate 1 lb. to 5 gals. water.....	16	3900	.4
4[1]	Copper sulfate, same as 4, but limed shortly after treatment.....	90	4700	1.9
5	Check plat. Untreated.....	678	3300	20.5

also to stop action of chemical. The seed came up about the same in all the plats except the unlimed half of the seed treated with copper sulfate. In this case the action of the chemical had been too severe, killing part of the seed and greatly retarding the germination of all by destroying the root end of the embryo. This seems to be a not uncommon effect of this chemical. The results show each treatment effective in lessening the amount of smut; but the hot water by far the most successful. The sprinkling methods, however, had been found to be less cumbersome. Here the seed, while not so thoroughly wet as in

the hot water treatment, was still dampened enough to require attention in drying or in sowing, if sown immediately.

In 1898 the experiments for comparing the best methods of treatment were conducted on a more extensive scale. The results are given in Table 11. Seed which had 10% smut in it the year before was used, and the same amount was sown on plats of one-seventeenth of an acre. Except the hot water, such treatment was by thoroughly sprinkling at the rate of between one and two gallons of liquid per bushel of seed. The seed was then placed in boxes and two days later planted, except

TABLE 11. VARIOUS TREATMENTS FOR PREVENTION OF OAT SMUT. 1898.

Plat.	Treatment given seed.	Smutted.	Total counts.	% smutted.
1	Corrosive sublimate, 1 lb. to 25 gals. water.	105	4000	2.6
2	" 1 lb. to 50 gals. water.	158	4000	4
3	" 1 lb. to 100 gals. water.	237	4000	5.9
4	" same as 2, planted immediately.	135	4000	3.4
5	Check plat. Untreated	230	4000	5.8
6	Formalin, 1 lb. to 25 gals. water	Not a smutted panicle.		0
7	" 1 lb. to 50 gals. water	21 smutted panicles in plat		0
8	" 1 lb. to 100 gals. water	506	4000	12.7
9	" Same as 7, but planted immediately	7 smutted panicles in plat		0
10	Check plat. Untreated	440	4000	11
11	Copper sulfate, 1 lb. to 5 gals. water	78 smutted panicles in plat		0
12	" 1 lb. to 10 gals. water. Unlimed	36	4000	.9
13	" 1 lb. to 10 gals. water. Limed.	22	4000	.5
14	" 1 lb. to 15 gals. water	125	4000	3.1
15	" Same as 12, but planted immediately	42	4000	1.1
16	Check plat. Untreated	357	4000	8.9
17	Ceres pulver, 1 lb. to 5 gals. water	56	4000	1.4
18	" 1 lb. to 10 gals. water	70	4000	1.8
19	" 1 lb. to 15 gals. water	78	4000	2.
20	" Same as 18, planted immediately	60	4000	1.5
21	Check plat. Untreated	316	4000	7.9
22	Potassium sulfid, 1 lb. to 5 gals. water	52	4000	1.3
23	" 1 lb. to 10 gals. water	72	4000	1.8
24	" 1 lb. to 15 gals. water	68	4000	1.7
25	" Same as 23, planted immediately	68	4000	1.7
26	Check plat. Untreated	202	4000	5.1
27	Hot water, 133° F. for 12 minutes	Not a smutted panicle.		0
28	" 131°–2° F. for 6 minutes	50 smutted panicles in plat		0

that one plat for each chemical used was planted immediately. This was done to determine whether or not the chemicals were used in strong enough solutions to injure germination of seed if left damp some time,

or whether or not the treatment was severe enough to kill the smut if seed was sown immediately. With the strengths used either method proved equally efficient and harmless. All treated plats came up before checks, and so far as could be told from a general examination no treatment had an injurious effect on germination, unless it was the stronger solutions of corrosive sublimate. Three strengths of each chemical were used to gain some idea as to how weak or strong the solutions could be made and still be efficient. Potassium sulfid and Ceres pulver gave about the same results as in 1897, cutting down the per cent. of smut considerably but in no case making it less than one or two per cent. Corrosive sublimate was not as effective as either of

TABLE 12. FUMES OF FORMALIN FOR PREVENTION OF OAT SMUT. 1898.

Plat.	Planted.	Treatment given seed.	Results.
29	April 15.	10 % formalin sprinkled at rate of 1 quart to 1 bushel, sacked and planted at end of 6 hours	Seed entirely killed.
30	April 16.	Same as 29, but planted at end of 24 hours.	Seed entirely killed.
32	April 26.	Same as 29, but planted at end of 11 days.	Seed entirely killed.
33	April 26.	One pint of oats wet with ⅛ pint of 25 % formalin and then placed in box and 7 pints of smutty oats placed on top. Planted 1 quart taken from top 11 days later.	No smut was found in this plat, and apparently the treatment had not injured germination of oats
34	April 26.	Same as plat 33, except ⅛ pint of carbon bisulfid was used.	Counts of 4000 panicles gave 151 smutty, or 3.8 %.
35	April 26.	Check plat. Untreated.	Counts of 4000 panicles gave 215 smutty, or 5.4 %.
36	May 10.	5 % formalin sprinkled at rate of 1 quart to 1 bushel, then sacked and planted at end of 24 hours.	Found no smut in this plat, but germination of seed was apparently injured by the treatment.
37	May 10.	2 % formalin sprinkled at rate of 1 quart to 1 bushel, sacked and planted at end of 24 hours.	Found no smut, but this and 36 planted too late to tell exact effect on seed
38	May 10.	Check plat. Untreated.	Counts of 4000 panicles showed 78 smutty or 2%.
39	May 17.	Same as plat 36, but planted one week after treatment.	Found no smut in this plat, but did not do as well as check.
40	May 17.	Same as plat 37, but planted one week after treatment.	Found no smut, but planted too late to tell effect on seed.
41	May 17.	Check plat. Untreated.	Counts of 2000 panicles gave 28 smutty, or 1.4 %.

these, and it has the further objection of being a deadly poison. The stronger solutions of copper sulfate were quite effective, and did not seem to injure the grain as in the preceding year. The formalin and hot water treatment gave perfect results in two cases, and proved their superiority over all others.

While the sprinkling method lacks the cumbersomeness of the dipping method, still it has about the same objection against it as regards wetting the seed. To make the treatment efficient, the sprinkling must be thorough, and this necessitates drying the seed afterward, unless sown immediately. Most seeders will not work well with wet seed. The character of formalin, as regards its very pungent fumes and its excellency as a fungicide, suggested that perhaps, if used in stronger solutions but not in sufficient quantity to dampen the seed, it might still destroy the smut without injury to the seed. Experiments along this line were conducted in 1898. Usually with the sprinkling method a gallon or more of the liquid is used per bushel of grain. In these experiments the rate was only a quart per bushel, which was not sufficient to wet the seed so but that it could be sacked and left without drying. Different strengths of solutions were used, the stronger proving fatal or injurious to the seed. Most of the treatments were made so late in the season that the exact effect on the seed and smut could not be told, since seed planted so late naturally does poorly and is likely to have less smut. In one or two cases, however, (see plats 33, 37, Table 12) some very suggestive results were obtained and offer encouragement for further investigation along this line. The results also show the comparative inefficiency of the fumes of carbon bi-sulfid in this direction.

Hot Water Treatment in southern Illinois. It was desired to find out exactly how this treatment would work under ordinary farm conditions both as to the prevention of smut and the practicability of the method. Accordingly arrangements were made in 1898 with four interested farmers in different localities in southern Illinois for the treatment of a limited amount of seed for them and a half a dozen of their neighbors. Southern Illinois was selected because here during the two preceding seasons the loss from oat smuts had been considerable. The arrangements made by the farmers for treating the seed varied somewhat, but ordinarily consisted of a fire out doors, two or three large iron kettles for heating the water, a couple of barrels for dipping the grain, and a supply of water. At one place steam was provided from a boiler by means of which a large tank of water was readily heated to the desired temperature. Except at Du Bois, where the size of the steam heated tank made it possible to treat two bushels, only one bushel, in a large coarse gunny-sack, was treated at a time. This was generally given a preliminary bath in a barrel of hot water before being placed in

the barrel at the required temperature. From one to four bushels were treated for each man, about sixty bushels being treated altogether.

The conditions were such as to test severely the feasibility of this method of treatment as an ordinary farm operation. The farmers were not usually provided with means for readily drying the treated seed and the season being a very damp one also made this more difficult. Rain delayed the planting in some cases for a month after the treatment. With a number the oats had germinated rather freely before planting, but this did not seem to have caused much subsequent injury. Usually the farmers reported the germination and stand of the treated oats as good and in advance of those not treated. No effort was made to have especial care used in the handling of the treated oats, and they were usually sown in a strip along the side of the untreated field.

Just before harvest the fields were all visited and the per cent. of smut in the treated and untreated oats determined. The details of the experiment are given in Table 13. In only two of the treated lots of seed was the per cent. of smut large enough to be determined, being practically nothing, and in those two it was much lower than in the untreated. On the other hand the season had not been so favorable for the development of smut, as the check fields only averaged about 4%. Even in those fields where it was least, however, one could easily detect the difference between the treated and untreated parts.

At each of the localities visited one lot of seed was treated by sprinkling with formalin, of the strength of one pound to about fifty gallons of water, using a gallon and a half of the liquid to the bushel. This treatment did not prove quite so effective as the hot water treatment, probably because the solution used was hardly strong enough.

Another point it was desired to bring out in these experiments was whether the crop resulting the second year from treated seed would be fairly free from smut, providing no special care were taken in the handling, planting, and threshing of the crop from treated seed. The data obtained on this point are not so extensive as desired, but those reporting stated that there was less smut in the crop which had received seed treatment the year before, than in that which had not. These results are promising for this procedure when it is remembered that the treated seed was nearly always planted side by side with the untreated and so was sure to have at least some smut blown on the seed in the field. If one wishes to try limited seed treatment to obtain clean seed for another year's use, there are two precautions that need to be taken that were not in these cases. First, the treated seed must be planted by itself, and, second, no other oats should be mixed in the handling, etc., with those of this crop. By watching his oats and applying such treatment when needed, a farmer should suffer very little from this foe and at the same time be at no very great trouble in keeping it down.

TABLE 13. HOT WATER TREATMENT FOR OAT SMUT CONDUCTED IN SOUTHERN ILLINOIS. 1898

No.	Name and Address.	Condition of seed.	Treatment.	Results of Treatment.		Check. Untreated.		
				Germination.	Amount of smut.	Smutty.	Total.	%
1	W. H. Symons, DuBois....	Badly smutted.....	134°–2° F, 10 min....	Good.....	Practically none..	309	4700	6.6
2	L. C. Bunce, DuBois.....	Smutted some.....	134 5°-129° F, 10 min.	Good.....	66 in 3400=1.9 %	389	3000	13.
3	Fred Fischer, DuBois	Same oats as 2.....	134.5°–130° F, 10 min.	Very nice.....	Practically none..	130	3000	4.3
4	Charles Seibert, DuBois....	Not badly smutted.	134°–130° F, 8 min....	Fair stand.....	Practically none..	83	2000	4.2
5	John Holbrook, DuBois....	Not very smutty...	134.5° 129° F, 8½ min.	Very well.....	Practically none..	Failed to	examine.	
6	Frank Kelsey, DuBois.....	Quite smutty.....	134.5°–132° F, 8 min..	Fairly well.....	Practically none..	Estimated	at	2
7	A. A. Hinkley, DuBois	Not known.....	134 5°–131° F, 8 min..	Good.....	Practically none .	100	5000	2
11	C. W. Mitchell, Irvington..	Not badly smutted.	129° F, 10 min.....	Spoiled by germination.	.....	.....	.....	....
12	A. B. Downs, Richview....	Badly smutted.....	130° F, 10 min.....	Failed to plant.....	.....	.....	.....	.. .
13	W. O. Brown, Irvington....	Somewhat smutted.	130° F, 10 min.....	Good	16 in 3000=½ %.	108	2200	4.9
14	Alex. Mitchell, Irvington...	Badly smutted.....	131° F, 10 min.....	Fine	Practically none..	66	2000	3.3
15	Frank Kagy, Kinmundy....	Very bad.....	131° F, 8½ min.....	Poor seed, failed to make	a stand. Treated	did best.	.....	....
16	A. J. Howell, Kinmundy...	Badly smutted	132° F, 7 min.....	All right.....	No smut.....	59	2000	3.
17	Chris. Shafer, Farina.....	Lots of smut.	131° F, 9 min.....	All right...	Practically none..	106	2000	5.3
18	Thomas Wade, Kinmundy..	Not very bad.....	130° F, 10 min.....	Oats failed to do well,	but treated came	up best..	.....	....
19	J. T. Dillon, Kinmundy....	Oats same as 18...	130°–1° F, 10 min. ...	Poor; good as untreated.	Practically free..	37	2000	1.9
20	Percy Balke, Kinmundy....	Badly smutted.....	130°–1° F, 10 min.....	Good.....	Practically free..	68	2000	3.4
21	Henry Balke, Kinmundy...	About 5 % smut...	131° F, 10 min.....	Good.....	Practically none..	98	2000	4.9
22	J. W. McCluer, Farina....	Mr. M. treated 18	bushels for himself...	.....	About free.....	123	2000	6.1
23	George Heth, Edgewood...	Not badly smutted	131°–3° F, 9 min.....	Failed to dry.....	.....	.....	.....	....
24	John M. Lieb, Edgewood...	Badly smutted.....	131°-3° F, 9 min.....	Good.....	Practically none..	40	2100	1.9
25	Fred Quade, Edgewood....	Not much smut....	130°–1° F, 9 min.....	Good.....	Found none.....	11	2000	.5
26	W. M. Quade, Edgewood..	Not bad.....	131°–2° F, 9 min.....	Not a stand; failed to	cover after sowing	.....	.....	....
27	J. P. Gillmore, Edgewood...	Same oats as 24....	131°–3° F, 8 min.....	All right.....	Practically none..	110	2000	5.5
28	Samuel Bartley, Edgewood.	About 10 % smut..	130° F, 8 min.....	Fine	Practically none..	110	2000	5.5
29	Joe Danks, Edgewood.....	Not very smutty...	131° F, 10 min.....	Good.....	Practically free..	41	2000	2.5

Conclusions from Prevention Experiments. From the results of the various experiments conducted, the following conclusions are made: 1. Seed treatment can be made very effective for prevention of oat smuts. 2. Of all the means tried, hot water and formalin proved the most efficient. 3. The sprinkling method with formalin, strength 1lb. to 40 or 50 gallons water, was by far the simplest of these two, and as such has much to recommend its general use. 4. The experiments conducted with stronger solutions of formalin and less amounts applied, leaving the fumes to act, suggest possibilities in this direction of importance, since in this way is eliminated the problem of drying the seed or the difficulty of handling it wet if sown immediately. 5. Limited treatment of only enough grain to obtain clean seed for another year is probably the best procedure in most cases, especially when the hot water method is used. 6. The smut that produces infection is chiefly that which is blown on the seed in the field and so unusual precautions in handling treated grain are hardly necessary. 7. But treated seed should always be sown by itself to give the best seed for another year, and in harvesting this grain care should be taken that no other oats become mixed with it.

SMUT OF TALL OAT GRASS.

Ustilago perennans, Rostr.

This is a smut that botanists formerly considered identical with those on oats, as it has much the same general appearance. It is less destructive to the flower parts than the loose smut of oats, being more like the hidden form in this respect. Usually the outer glumes are not disturbed and even the destruction of the parts within is not generally so complete. As the glumes are transparent the mass of spores, which is not very dusty, shows through, having a dark olive brown color.

Under the microscope the spores appear about like those of the loose smut, being somewhat smaller, 5-7μ, in diameter. Brefeld* states that their germination is exactly like that of oat smuts and he does not consider this as a distinct species.

The mycelium, like its host, is perennial so that the smut will appear year after year, and because of this the culms from a smutted plant are more uniformly smutted than in those cases where the host is an annual. In one case a count was made of fifty smutted culms, all apparently from the same plant. Very few panicles appear the first

*Brefeld classifies the smuts that were formerly placed under *Ustilago segetum* as follows: The loose smut of wheat and barley as *Ustilago Hordei*, Brefeld; the covered smut of barley as *Ustilago Jensenii*, Rostr.; and the smut on oats and oats grass as *Ustilago Avenae* (Pers.) Jens., the last two species being closely related. He bases his classification largely on the results of cultures of spores in nutrient solutions.

season, but the smut may show in these. The second year the plants normally produce their flowers and from this on the smut may be quite common in them.

This plant is not often raised in this state and the few cases where the smut has been found have been in the Experiment Station plats. It has been noticed here for the past ten years, though never very abundant till in 1898. As the host is raised for hay and as the smut always occurs in the panicles, the financial loss that it causes is not so great as it would be if the plant were a cereal. No experiments have been conducted, at least in this country, for prevention through seed treatment, but as the host and its smut are closely related to oats and its smuts, it seems very likely that such treatment would prove successful.

LOOSE AND COVERED SMUTS OF BARLEY.

Ustilago Hordei (Pers.) Kell. & Sw. *Ustilago nuda* (Jens.) Kell. & Sw.

Life History. Upon barley there are found in this state two smuts that, until about ten years ago were not distinguished as distinct species and were even thought to be identical with the forms on oats, etc. The general appearance of these smuts is such as to lead one to suppose them to be the same, since they both occur as dusty outbreaks which more or less completely destroy the flower parts. They are known as loose and covered smut. The former matures its spores, which are of a dark olive brown, to the destruction of the flower parts of an infected spike, and with time these are dissipated until nothing remains but the naked rachis. The latter, whose spores are of a purplish black color, has these outbreaks protected by a membrane which thus more permanently holds the spores together.

Under the microscope the spores of both forms are somewhat lighter colored on one side, but differ by the covered smut having sub-spherical, dark, smooth spores, while the other has oval to sub-spherical, lighter, minutely echinulate ones. The spores of the covered smut are said in germination to produce an abundance of sporidia much after the manner of oat smuts, while those of the loose smut produce only infection threads, thus closely allying itself to the loose smut of wheat. Both forms gain entrance into the host through the young tissues of the germinating seed, the mycelium following the upward growth and producing its spores in the spikes at the time the flower parts are developing. Jensen has shown that it is the spores that fall down between the open glumes in the field that are the chief source of infection, and it is very likely that with the loose smut these spores germinate at that time and infect the seed coats with a hibernating mycelium that the ensuing year gains entrance to the seedling. This would explain the failure of the ordinary methods of seed treatment to prevent the smut.

Damage. These smuts cause comparatively little financial loss in this state, primarily because the barley crop is not very large, its value for 1897 being estimated at but a little over $130,000. The collections of these smuts, because of this infrequency with which barley is grown, have been comparatively few, chiefly those made from barley grown on the Experiment Station grounds. No complaint has been received from farmers concerning them. It would seem from the few fields examined that they have been even less abundant here than the loose smut of wheat. However, they are quite common in those countries where barley is extensively grown and seem to be nearly as injurious there as the smuts of oats.

Prevention. Very little has been done in this country looking toward the prevention of these smuts. Jensen, of Denmark, however, has experimented along this line and has found that the covered smut could be prevented by the ordinary hot water treatment of seed, but that the loose smut was not prevented by such treatment. He found, though, that it could be controlled by a modification of this method, a more severe treatment in which the seed is first soaked for four hours in cold water, then allowed to stand damp four more in sacks, after which a hot water treatment at 126°-8° F. is given for five minutes. The necessity for this difference in treatment to prevent the two forms is probably caused by the development of the hibernating mycelium in the loose smut, the destruction of which is accomplished only by the severer treatment.

LOOSE SMUT OF WHEAT.

Ustilago Tritici (Pers.) Jens.

Life History. This is another smut until recently classed with the preceding forms, because of the general similarity in appearance of the outbreaks and spores. The affected spikes have their flower parts changed into a dusty, dark olive brown mass very much like loose smut of barley. Usually the destruction is so complete that there eventually remains only the naked rachis.

The appearance and germination of the spores, and in fact the whole life history indicate its close relationship to this smut of barley. It also seems to be true that infection first really takes place in the field by the development of a temporary mycelium in the seed coats.* This will explain several points peculiar about the fungus; namely, its ability to get along without sporidia, low percentage of germination of spores, the few cases of infection (one per cent.) that Jensen obtained when mixing

*Massee states that frequently with *Ustilago Vaillantii* the mycelium penetrates the coats of seeds not destroyed by smut, and the next year these develop smutty plants. Maddox inoculated wheat spikes with smut one year without the grain becoming smutty, and from this seed produced smutty plants the next year.

smut with mature seed, and the failure of the ordinary methods of seed treatment. The soft young wheat kernels at the time the smut first appears seem also to offer a good chance for such infection.

Damage. As with oats the damage consists in the destruction of the grain and the partial stunting of the culms. Wheat smut does not seem quite so abundant in this state as oat smut, though it is more or less common in most fields. Neither does wheat occupy quite so prominent a feature in our agriculture, especially of late years. For these two reasons the financial loss is not so great as from the oat smuts. It is serious enough, however, to demand attention.

Very few counts to determine the per cent. of smut in wheat fields have been made, as little wheat is raised in the vicinity of the Experiment Station. In 1892 counts made in several plats of one variety grown at the Station showed an average of 5%, while another variety was estimated to have less than ½%. Counts made in two fields in the vicinity showed a presence of 5% in one case and 15% in the other, this latter having been selected as one containing an unusually large amount.

Prevention. No experiments of value for prevention have been tried here and those conducted elsewhere have generally given negative results. The experiments at the Ohio Experiment Station with the modified hot water treatment, however, show that seed treatment is effective when made severe enough to injure, in part, the germination of the seed. The treatment recommended is to soak the seed four hours in cold water, then to let it stand four more wet in the sacks, after which to give hot water treatment of 133° F. for five minutes. As this kills part of the seed, one and a half times the usual amount should be sown per acre. On account of the severity of the treatment, it would seem advisable to treat only enough to obtain clean seed for another year's use.

STINKING SMUT OF WHEAT.*

Tilletia foetens (B. & C.) Schroet.

Life History. This smut merely transforms the grain into a slightly enlarged smutted kernel, leaving the glumes entirely free, so that an infected spike has much the same appearance as a free one. For this reason the smut is easily overlooked in the field. It can sometimes be detected by the color of the infected spike and very often by the presence of the smut eating beetle. Its odor is quite characteristic, as it is very fetid, and is retained for years by the smutted kernels.

*There is another stinking smut, *Tilletia Tritici* (Bjerk.) Wint. that has been occasionally reported in this country. So far this has not been found in this state, though it very likely occurs here, as specimens have been sent in for determination from adjacent states. The two can be told apart only on microscopic examination, *T. Tritici* having prominently reticulated spores, while those of *T. foetens* are smooth. They seem to have much the same life history.

This smut is entirely different, botanically, from any of the preceding species. The spores are comparatively quite large, mostly 18-24 μ in diameter, are smooth and chiefly sub-spherical or spherical in shape. In germination they send out a pro-mycelium two to several times the length of the spore, upon the end of which are produced a number of long, slender sporidia tapering toward the free end. These soon assume a more or less bow shape and from the center of the convex side give rise to a short protuberance, which if rightly situated coalesces with a similar protuberance from an adjacent sporidium. There are now developed either infection threads or secondary sporidia from the resulting outgrowths. The secondary sporidia may in time produce infection threads. By these the fungus gains entrance into the germinating seed and through the developed mycelium follows the upward growth of the plant, eventually forming its spores in the seed producing parts.

Damage. This smut is one of the best known, and, in large wheat districts of this and the old world, is one of the most destructive smuts. Although it has probably long occurred in this state, the first collections in the herbarium were made in 1892 from the Experiment Station plats. A careful examination of these the year or two previous had failed to show the presence of this fungus, but in this year it was found in small amounts in several plats, and in one plat counts showed 4% present. The same year N. W. Graham complained of its being very bad in the neighborhood of Carbondale. He wrote: "For several years past we have had almost no smut in this county, but this year it is worse than I ever knew it." He sent several thousand infested spikes gathered from a single acre of land. Inquiries have shown that it has occurred in various parts of the state, but at present does not seem to be attracting much attention, probably because wheat is not now extensively raised except in southern Illinois. It is a fungus, however, that undoubtedly in some years and in certain fields causes considerable loss. The fungus is also objectionable because in flour made from very smutty wheat more or less spores get into it, making it of an inferior grade.

Prevention. In the fall of 1895 the Station made the only experiment it has conducted for the prevention of this smut. Very smutty seed was mixed with an additional amount of smut and then half of it was treated with hot water at 132°-4°F. for fifteen minutes, after which both parts were planted in small plats side by side. Much of the wheat in both plats was winter killed, but all of the spikes in both plats were counted, showing the treated plat entirely free from smut, while the check plat contained 3%. Extensive experiments have been conducted by the Experiment Stations of Kansas, Indiana, and North Dakota and their results show that this smut can be prevented by the hot water treatment. The copper sulfate, or blue stone treatment, has long been used, though frequently it acts severely on the seed. The North Dakota

Station has experimented more than any of our other stations with different methods of preventing this smut, and it now recommends the thorough sprinkling of the grain with formalin (1 lb. to 50 gallons water) and leaving in piles over night.

SMUT OF INDIAN CORN AND TEOSINTE.*

Ustilago Zeæ (Beckm.) Unger.

Life History. Corn smut apparently breaks out on any part of the plant except the silks of the ears and the underground roots, though its presence on the internodes is generally limited to its spreading from an infection at the node. The attack may be quite general though never so abundant that the whole plant becomes distorted, or it may be limited to a single small outbreak. These smut balls vary from quite prominent distortions several inches in diameter to those only the fraction of an inch, the largest generally appearing in the ears and the smallest in the leaves and tassels. The smut does not make its appearance until the plants have become rather large, the first outbreaks showing usually on the leaves. The affected parts often assume quite abnormal shapes, as for instance the filaments may become greatly enlarged beyond the size of the anther, this remaining free from the fungus, or the individual kernels of the ear may become greatly distended. When the smut-ball first appears it is protected by a whitish membrane within which is a moist mass of half ripe spores, fungous threads, and some plant tissues; but as it matures the whole is changed into a dusty mass of spores and becomes more or less dissipated in time.

The spores are of rather large size, chiefly 8-13μ, and mostly subspherical in shape, though occasionally, especially through pressure, they assume a variety of shapes. They are of a black brown color in mass. Their outer cell wall is prominently and abundantly provided with echinulations. They germinate readily in nutrient solutions at almost any time of the year. In water, however, this germination can not so surely be depended on, though sometimes beginning before the end of twenty-four hours. A rather elongated four-celled pro-mycelium is developed which may run out into a quite elongated thread. Occasionally the pro-mycelium becomes branched, especially at the base. Terminal and lateral sporidia are formed; but if excluded from air these generally soon fall off and are not produced very abundantly. When the germ threads reach the air, however, the sporidia are produced very

* The smuts occurring on these two hosts are undoubtedly the same, as is shown by the character of the outbreaks and the appearance and germination of the spores. Teosinte is rarely grown here except as a curiosity and the only collections of smut on it have been at the Exp. Stat. The following treatment relates only to the smut as it occurs on corn.

abundantly in simple or branched chains that remain attached to the spore. Often the pro-mycelium becomes detached near its base, and continues its development alone. The sporidia are somewhat fusiform bodies that vary considerably in size, very often it being difficult to tell them from the detached pro-mycelia. In germination they send out small bent infection threads. The germination of the spores is much the same in a nutrient solution, of course being much more luxuriant and abundant. The sporidia in Cohn's modified solution are produced in such abundance by budding as to form a conspicuous white crust or sediment. On the whole corn smut is more luxuriant in the production of sporidia than any of the other smuts described here.

The reason for this abundance of sporidia and their preference for aerial formation is explained when the manner by which they infect their host is considered. This takes place through the very young parts of the plant above ground, and not, at least to any extent in nature, through the germinating seed, as is the case with our other smuts. This manner of infection to be successful requires an abundance of infecting bodies and the aid of the wind. As the exposed parts of the plant are too old for infection there can be little doubt that water in the shape of rain and dew is a prominent factor in carrying down the germs that are blown on the plant to points young enough for infection. After gaining entrance the fungus has to contend with the rapidly maturing tissues, and so it becomes localized and rapidly passes through the mycelium to the spore stage. The time taken for this most likely varies somewhat with the organ infected, probably extending from about ten days to three weeks. In the leaves this maturing of tissues is the most rapid and, so while they are the most exposed parts of the plant, they usually show the fewest outbreaks. Other parts, as the ears, that are slower in development and thus more open to attack, are provided with greater protection against the presence of the germs. Of all the parts the axillary growths, found wrapped up by the bases of the leaves, are the most susceptible to infection, probably because they remain so long in their nascent condition and at most develop only weak tissues. They are also situated very favorably for having germs washed down on them. An inspection of the tables shows that most of the smutty outbreaks occurred at these lower nodes. When the plants are young, either from more rapid development of the parts or their greater protection, they seem more exempt from infection than at the time they have about made their full growth, just before the tassels are protruded.

Damage. As the grain is the chief object for which corn is grown, one can properly measure the injury of the smut by its action on this part alone. This injury manifests itself both directly and indirectly. The smut, for instance, may break out in the ear itself totally destroying it. The effect is then direct and easy of determination. The injury is

still direct when the ear is only partially destroyed, but the estimation of damage is more difficult. This, however, is not the greatest difficulty in the way of determining the damage inflicted. A glance at the tables given shows that the outbreaks in the ears are few compared with the total number. There must be determined the indirect effect that such adjacent infections have on the number and size of ears produced. Such complications make it impossible to determine the damage after the manner employed with oats smut, by determination of percentage of smutty stalks.

The proper way for estimating this loss is to determine the per cent. of smutted stalks in a field and then from a representative and sufficiently large area to determine separately the yield from the smutty and the free stalks. Hitchcock, of Kansas, found that the difference in yield, in one very smutty field, between the free and smutty stalks was one-third. This, however, is a difference that is variable and may not correspond with the amount of smut, as a field may have considerable and still be little damaged by it. This is shown in the case reported in Table 17, where an effort was also made to determine the difference in yield between the smutty and free stalks. In this case the difference, 8%, which was determined by number of ears rather than by weight, showed but little in favor of the free stalks. As this plat had only 20% of the stalks smutty, the total loss did not exceed 2%. That this was so low was due to the fact that while there was a large number of smutty outbreaks very few of them occurred on the ears. The data obtained is given in Table 14. That this loss was largely confined to the stalks that

TABLE 14.- EFFECT OF CORN SMUT ON NUMBER AND SIZE OF EARS.

Condition of stalks.	Total stalks.	% of stalks.	Stalks without ears.	% without ears.	Large ears		Medium ears.		Small ears.		Ears.	
					Number.	Ratio per 100 stalks	Number.	Ratio per 100 stalks	Number.	Ratio per 100 stalks	Total.	Ratio per 100 stalks
Free	247	80	53	21	52	21	87	35	52	21	191	77
Smutty	60	20	12	20	13	21	25	41	5	9	43	71

TABLE 15. AMOUNT OF SMUT ON CORN AS AFFECTING NUMBER AND SIZE OF EARS.

Condition of stalks.	No. stalks	% stalks	Number of ears.				Ratio per 100 stalks
			Large	Medium	Small	Total	
Badly smutted	6	10	0	0	1	1	16
Moderately smutted	15	25	2	8	2	12	80
Little smutted	39	65	11	17	2	30	77

were badly smutted, though it apparently affected the size of the ears in the moderately smutted plants, is shown by Table 15, in which is given

the number and character of the ears on the stalks badly, moderately, and but little smutted.

On the other hand the loss that occurred in the plat reported in Table 16 was very great, as here many of the smutty outbreaks occurred in the ears. On the whole, however, we are inclined to believe that the loss caused by this fungus is generally over-estimated. From our examination of fields we should judge that it usually ran from ½% to 5%, and that the loss for the whole state, year after year, is probably less than 2%. That this is so small is fortunate, since corn is by far our most valuable crop, that of 1898 being estimated at $50,000,000.

EXPERIMENTS.

Conditions, etc. Field experiments with corn smut were carried on from 1895 to 1898. Data concerning conditions and results of these experiments are given in Tables 16-24. Spores were used as the infecting agent, and unless otherwise stated were from the same host (sweet corn smut with sweet corn, etc.), and were taken from the previous year's crop. It was tried to make the conditions exactly the same for all plats of a given table, except those mentioned under heading of treatment. The examinations of the plats were made after the smut ceased to appear, unless it was in those of Table 16, where the first plats were probably examined a little too soon and, as it took a week between examination of first and last plats, this may account in part for the higher showing made in the later ones. The experiments were begun under the impression that the chief manner of infection was through the germinating seed either from attached germs or those in the ground, and so the experiments for the first two years were largely along lines thus suggested.

To judge correctly of the results of these experiments is more difficult than with related experiments with oats smut, since with the latter conditions can be made such that the checks are free from smut. With corn there is a variable amount of smut present in field experiments, no matter what the treatment. This makes it difficult to determine what is due to the specific treatment unless it is very marked or localized. The plats receiving no treatment have been used as checks, and the percentage of smutty stalks has been taken as a standard of comparison. Since infection is local, however, two distinct outbreaks on different parts of the same stalk would mean as much as a single outbreak on each of two stalks, though not showing the same in the percentages. This condition is taken into consideration by the determination of total distinct outbreaks in each plat and their enumeration in ratios of so many per hundred stalks. These ratios, however, generally show about the same relationship between different plats as do the percentages. As the position of the smutty outbreak may have some relation to the manner

of attempted infection, there is given in each case the number of outbreaks on the different parts of the plant. On account of the differences that might be made by season, land, etc., one can compare with each other only treatments in the same table, though the general idea of a treatment may be gained from its results from year to year. In order to determine the variation that might occur within the same plat, so as to know more fully how to judge of variations between plats, these observations were made for each row, though in the tables only the totals for the plat are given. This variation within plats was sufficient to make it necessary to neglect all but the prominent variations that occurred between plats. Those that show smut evidently produced by the treatment are marked with bold faced type.

One of the most prominent things that suggests itself from a review of these tables was the common failure to produce any great variation in amount of smut due to the treatment given. Possibly in some cases this may have been due to the use of spores and might have been different had sporidia been used, as was done by Brefeld in his experiments, since corn smut spores do not always germinate in water. However in most of the cases failure of infection can not be attributed to the use of spores but to the fact that it does not commonly take place in nature under such conditions. For convenience the discussion of the results and observations made in their collection will be given under the following heads: Prevention, Infection, Relation to Land, etc.

Prevention. The experiments show emphatically that this smut can not be prevented by seed treatment. This is in accordance with the results of experiments that have been reported by others. The experiments also show that seed treatment has no influence in reducing the amount of smut. In the nine different comparable cases in the following tables of ordinary seed treated and untreated the average number of smutty outbreaks in the two cases is almost exactly the same, while in the individual cases sometimes the treated and sometimes the untreated plats gave a little higher number. The same is true of the cases where the seed was mixed with smut and then part of it treated.

The experiments in 1895 in treating the soil with chemicals showed no evidence that this was effective in reducing the amount of smut, though it did injure the germination of the seed in one case. The spraying experiments with Bordeaux mixture, while not very extensive, did not show any results, unless it was in case of plat 4, Table 18. Nothing can be expected of this treatment, however, as it is impracticable. Neither does the spray readily adhere to the leaves, and as it does not reach the parts through which infection takes place it can act only in a general way.

Selection of land is not a means for prevention, as smut appeared in all of the different plats, though from the observations made in this

TABLE 16. FIELD CORN EXPERIMENTS WITH SMUT, ON PASTURE JUST BROKEN AND WITH CORN PLANTED VERY LATE. 1895.

Plat.	Treatment.	Rows.	Total stalks.	Free stalks.	Smutty stalks.	% smutty stalks.	Smutty outbreaks.	In lower nodes.	In upper nodes.	In leaves.	In matur-able ears.	In tassels.	In husks.	In suckers	Rate of out-breaks per 100 stalks.
1	Seed treated with hot water (135° F for 15 min.)	1- 4	404	302	102	25	122	50	3	1	66	1	0	1	30
2	Seed mixed with smut	5- 8	539	394	145	27	207	121	9	1	75	1	0	0	38
3	Seed mixed with smut, then hot water treatment (135° F for 15 min.)	9-12	576	426	150	26	211	125	8	0	77	1	0	0	37
4	Hot water treatment (135° F for 15 min.) Sweet corn smut placed on young plants before they appeared above ground. Last ¼ not treated with smut	13(¾)	74	56	18	24	24	} 25	0	0	12	0	0	0	} 33
5															
6	Hot water treatment(135°F for 15 min.) Sweet corn smut placed on underground parts just after plants appeared above ground	13(¼)	35	24	11	31	13								} 37
7	Hot water treatment(135°F for 15 min.) Sweet corn smut placed in water on leaves just after plants appeared above ground	14	131	97	34	26	50	30	1	0	19	0	0	0	38
8	Hot water treatment (135° F for 15 min.) When plants were in ear but rather young mutilated plants badly by tearing and pulling off different parts.	15-16	311	230	81	26	117	63	3	0	50	0	1	0	38
		17 Before mutilation													
		After mutilation	174	128	46	26	58	37	1	0	20	0	0	0	33
		17	**174**	**99**	**75**	**43**	**107**								**61**
9	Seed treated with hot water (135° F for 15 min.)	18-19	329	234	95	29	137	90	4	1	42	0	0	0	42
10	Seed treated with hot water (135° F for 15 min.) then mixed with sweet corn smut	20-23	589	406	183	31	274	188	8	1	76	0	1	0	47
11	Seed mixed with smut, then treated with hot water (130° F for 15 min.)	24-27	688	475	213	31	318	202	6	2	108	0	0	0	46
12	Seed mixed with smut, then treated with hot water (140° F for 15 min.)	28-30	412	293	119	29	198	134	10	0	53	0	1	0	48
13	Seed mixed with smut, then treated with hot water (120° F for 15 min.)	31-34	592	380	212	36	336	194	10	0	124	6	1	1	57
14	Seed mixed with smut, then treated with hot water (145° F for 20 min.)	35-38	376	273	103	27	147	100	20	0	26	0	1	0	39
15	No treatment whatever	39-44	933	586	347	37	519	294	16	2	203	1	3	0	56
16	Counts made in rows 5, 10, 15 of adjacent corn with conditions of land, etc., same but seed planted in season		350	309	41	12	45	36	0	0	8	1	0	0	13

Average outbreaks per hundred stalks for all plats except those (in bold face type) influenced by treatment . . . 43.

connection there is no doubt but that this may have some influence in determining the amount of smut. It would seem, as claimed by Brefeld, that the presence of manure is an important factor in this case and also whether there had been a very smutty crop on the land the year before.

There is no doubt but that different varieties vary somewhat in their resistance to infection. Such difference is undoubtedly due to the manner of maturing their tissues, closeness with which parts envelope young tissue, rapidity of growth, etc. Sweet corn is said to smut easier than field, and it was noticed that those varieties of field corn that were slow in maturing or of rank growth, as Giant Mexican, were most inclined to become smutty.

Infection. The sum total of all of the experiments to infect the plants before they appeared above ground was of a negative character. Mixing spores with the seed was just as apt to give a crop as free from smut as to use ordinary or even treated seed. These failures to influence amount of smut through seed treatment can not be attributed to lack of germinating spores, for in 1897 where smut was mixed with manure and placed around seeds there was still no evident increase. The experiments in plats 12-13, Table 24, indicate that infection does not occur by means of a latent mycelium that might be formed in young seed developed in contact with smutty outgrowths on the same ear.

The spraying of spores on the young parts of the plant during different stages of its growth gave no very evident signs that the per cent. of smut was thereby increased, though in the case of plat 3, Table 24, where the spores were in manure water there may have been some slight infection from this treatment. In all these cases the spores were sprayed down in abundance between the youngest unfolded leaves. As explained before this failure to infect may have been partially due to lack of germination of spores.

The writer's attention having been called to the fact that smut was very common on injured places, especially noticeable in detasseled corn, a number of experiments were carried on in this direction. In the cases where the plants were mutilated young, when a few inches to two or three feet high, there was no evidence that the amount of smut was increased. Also when the plants were mutilated when rather mature (after appearance of tassels and corn changing from milk to dough stage) the results were negative. In the cases where mutilation, including usually more or less detasseling, was made at about the time for appearance of the tassels, the effect was usually shown by the increase of smut on such plants. Thus in 1895, Table 16, plat 8, the plants were so treated after determining the number of smutty stalks and outbreaks and when it was thought most of the smut had made its appearance. Counts made on the same row two weeks later showed almost double the number of smutty stalks and outbreaks. All of these could not, how-

TABLE 17. FIELD CORN EXPERIMENTS WITH SMUT, USING LAND WHICH THE YEAR BEFORE HAD A SMUTTY CROP. 1895

Plat.	Treatment.	Rows.	Total stalks.	Free stalks.	Smutty stalks.	% smutty stalks.	Smutty outbreaks.	In lower nodes.	In upper nodes.	In leaves.	In maturable ears.	In tassels.	In husks.	In suckers.	Rate of outbreaks per 100 stalks.	Average outbreaks, etc. 26
1	Ordinary seed. No treatment...	1- 8	596	526	70	12	91	33	12	13	6	24	1	2	15	
2	Seed treated with hot water (135° F. for 15 min.).....	9 16	646	545	101	16	159	75	16	21	5	39	1	2	25	
3	Seed treated with hot water (135° F. for 15 min.) and ground around seed sprayed with Bordeaux Mixture..	17 21	318	258	60	19	90	40	8	18	0	23	0	1	28	
4	Seed mixed with smut..	22 29	606	469	137	23	213	98	17	21	2	72	0	3	35	

TABLE 18. SWEET CORN EXPERIMENTS WITH SMUT, USING CULTIVATED LAND NOT PLANTED IN CORN FOR YEARS. 1895

1	Ordinary seed. No treatment.....	1- 6	107	93	14	13	14	0	1	1	8	0	0	4	13	
2	Seed treated with hot water (135° F. for 15 min.).....	7-12	62	54	8	13	8	1	1	0	5	0	0	1	13	
3	Seed mixed with smut, then treated with hot water (135° F. for 15 min.).....	13-18	110	103	7	6	7	1	0	1	4	0	0	1	6	10
4	Seed treated with hot water (135° F. for 15 min.) Plants sprayed 3 times during season with Bord. Mixture....	**19-24**	**72**	**71**	**1**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	
5	Seed treated with hot water (135° F. for 15 min.), then mixed with field corn smut.....	25-30	84	78	6	7	8	1	0	0	5	0	0	2	10	

TABLE 19. SWEET CORN EXPERIMENTS WITH SMUT, USING CULTIVATED LAND WHICH YEAR BEFORE HAD SWEET CORN WITH SOME SMUT. 1895.

1	Ordinary seed. No treatment.....	1- 4	65	60	5	8	8	4	0	3	0	0	1	0	12	
2	Seed treated with hot water (135° F. for 15 min.).....	5- 8	94	82	12	13	16	5	1	4	4	1	0	1	17	
3	Seed treated with hot water (135° F. for 15 min.) and ground around seed sprayed with Bord. Mixture.	9-12	79	72	7	9	8	7	0	0	1	0	0	0	10	11
4	Seed treated with hot water (135° F. for 15 min.) Ground sprayed. Plants sprayed 3 times with Bord. Mixture.	13-16	72	67	5	7	5	2	1	0	2	0	0	0	7	
5	Seed mixed with smut.....	17-20	113	105	8	7	12	6	0	0	4	0	1	1	11	

ever, be attributed to the mutilation, as counts on an unmutilated row also showed an increase, though not nearly so large. Table 24, where all of the plats were detasseled to prevent interfering with another corn experiment, gives the most striking illustration of this treatment. Here the smut appeared just at the point where the tassel was removed, and of all of the outbreaks in the plats 60% were of this nature.

Of all the experiments the most evident results were obtained when the plants were mutilated and then smut spores sprayed on those places. When the plants were young or old, as in case of mutilation alone, but little more smut was produced; but when they were about the tasseling stage, and when ears were quite young, the treatment had effect. This is very prominently illustrated in the results in Table 23, plats 2-4. Here spores, in water in two cases and in manure water in one case, were sprayed on the young parts of the tassel then fairly well protruded, without mutilation, and on most of the young ears, after tearing open the enveloping leaves and husks and so mutilating them and also the kernels somewhat. The plats were first examined between three and four weeks later, and the smut was then somewhat prominent, showing it had developed in less than three weeks. Later final examinations showed no unusual amount of smut in the tassels or upper parts exposed to the spores without mutilation, but the outbreaks in the ears were unusually numerous, and chiefly localized at point of mutilation. The three plats gave one hundred and three smutted ears out of a total of one hundred and ninety-nine, or over 50%. The check plat gave only one smutted ear. Plate J shows a photograph of the infected ears from plat 2 of this experiment. The sweet corn plats (7-10, Table 23) were treated the same but gave no results. Evidently the ears had matured beyond the infection stage when the spores were applied. This resistance due to maturity of tissues is shown by the experiment in 1898 (Table 24, plats 9-11) where ears were mutilated late, (kernels changing from milk to dough stage) and spores applied, and no successful infection took place.

It seems to the writer that the general failure to infect by spraying spores on unmutilated young parts and on young plants even when mutilated was due, in part at least, to the lack of vigorous germination of spores; while with those plants that were mutilated when abundance of sugar was being carried into tassels and ears there was formed a more abundant and sweeter exudation in which the spores applied, or the germs carried there by the wind, multiplied through sporidia to such an extent that infection was more easily accomplished.

Relation to Land, etc. The difference in the manner of infection puts corn smut in a somewhat different relationship to such environmental conditions as are produced by land, season, etc. It is difficult to judge of the weight these have in determining the amount of smut

TABLE 20. FIELD CORN EXPERIMENTS WITH SMUT, USING SOD, JUST BROKEN, NOT MANURED OR USED AS PASTURE. 1896.

Plat.	Treatment.	Rows.	Total stalks.	Free stalks.	Smutty stalks.	% smutty stalks.	Smutty outbreaks.	Average outbreaks, etc. 11					
								In lower nodes	In upper nodes.	In leaves.	In maturable ears.	In tassels.	Rate of outbreaks per 100 stalks
1	Seed treated hot water (135° F. for 15 min)	1 2	155	141	14	9	15	10	1	1	3	0	10
2	Seed treated as above, and smut placed on young plants before appearing above ground	3	70	63	7	10	7	4	2	0	1	0	10
3	Seed treated as above, smut placed on young parts just after plants appeared above ground	4	72	67	5	7	7	5	1	0	1	0	10
4	Seed treated as above, smut placed on young parts when plants were one to two feet high	5	70	68	2	3	2	2	0	0	0	0	3
5	Seed treated with hot water (135° F. for 15 min.)	6-7	150	134	16	11	20	8	8	0	3	1	13
6	Seed mixed with smut, then treated with hot water (135° F. for 15 min.)	8-10	217	201	16	7	17	10	4	0	3	0	8
6	Ordinary seed, with smut placed on young parts just before tasseling, July 9	11	66	60	6	9	6	5	0	0	1	0	9
7	Ordinary seed. No treatment	12-13	135	112	23	17	25	10	7	1	7	0	19
8	Seed mixed with smut	14-16	232	214	18	8	22	12	3	0	7	0	9
9	Seed mixed with smut. Plants mutilated June 12, 27, and July 7	17	62	56	6	10	7	3	3	0	1	0	11
10	Seed mixed with smut. Plants mutilated just as tassels were first appearing, July 7	18	72	64	8	11	9	5	1	0	2	1	13
11	Seed mixed with smut	19	108	93	15	14	17	13	3	0	1	0	16
12	Seed treated with hot water (135° F. for 15 min.) but planted very late, June 12	20-22	120	114	6	5	6	4	2	0	0	0	5
13	As in plat 12, but smut from this year's crop placed on young parts when about a foot high	23	46	45	1	2	2	0	0	0	0	2	4
14	Ordinary seed, but planted very late, June 12	24-27	219	215	4	2	4	1	3	0	0	0	2

since the period for which corn can be infected extends over such a comparatively long time, while, on the other hand, the struggle between the host and parasite for supremacy after infection is reduced to a short time. The conditions that insure or prevent primary entrance are no doubt of much greater importance than those that favor or hinder the development of the fungus afterward. It has been shown that the sporidia are the active agents in this primary infection, that their points of entrance are the aerial parts of the plant and that they depend on the wind as a carrying agent. Brefeld claims that manure is a hot-bed for production of sporidia. By such means no doubt their number is so greatly increased that this offsets to a great extent the disadvantage of aerial infection. It also explains why land can not be selected that will be entirely free from smut, for, while there might be few if any germs in it, the wind may blow such to the corn. It also explains, on the other hand, why more smut may be expected in one place than another if the conditions for multiplication of sporidia are more favorable in one than the other.

It was to determine, if possible, the effect of such external influences that note was made in each experiment of the character of the land employed, and this was varied as much as possible. An examination of the averages given in each table (these determined by using averages of all the plats except those influenced by treatment) shows that there were but two cases where there was an unusually large amount of smut. While both of these occurred the same year, the season could hardly be held responsible since other plats that year showed no unusual amount.

The worst smutted corn was that from which data are given in Table 16. This was as smutty corn as we have ever seen, averaging forty-two outbreaks for every one hundred stalks. From a fifth of an acre all of the smut was gathered and found to weigh 191½ lbs. or nearly half a ton per acre. (See Plate K for photograph.) The land had not been in corn in recent years, but had been used as a pasture for cattle, including the previous fall and winter when corn stalks had been fed to them on the further end. Early in the spring the ground had been broken and got in as good shape as possible for sod land the first year. Planting the corn was unavoidably delayed until June 15th, and this lateness of planting, etc., had its effect on the growth and yield of the corn, though it matured after a fashion. None of the smut treatments had an especial effect, except in the case with mutilation. The plats all gave a large amount of smut, showing general contagion, and developed an unusually large number of smutty ears. From all of the data gathered there were two things that might have had an influence in producing this unusual amount of smut. First, the land had been used as a pasture up to the time it was broken and so had more or less fresh

TABLE 21. FIELD CORN EXPERIMENTS WITH SMUT, USING LAND IN CORN LAST YEAR. 1896.

Plat.	Treatment.	Rows.	Total stalks.	Free stalks.	Smutty stalks.	% smutty stalks.	Smutty outbreaks.	In lower nodes.	In upper nodes.	In leaves.	In matturable ears.	In tassels.	In aerial roots	Rate of outbreaks per 100 stalks.	Average outbreaks, etc., 10
1	Seed treated with hot water (135° F. for 15 min.)	1- 6	923	849	74	8	82	39	20	0	13	9	1	9	
2	As in plat 1, but this year's smut placed on young parts when about to tassel, July 9	7	179	167	12	7	16	6	4	1	5	0	0	9	
3	As in plat 2, but plants badly mutilated by detasseling, etc., before placing smut on these young parts, July 16	**8**	**177**	**146**	**31**	**17**	**35**	**21**	**8**	**1**	**4**	**1**	**0**	**20**	
4	Seed mixed with smut, then treated with hot water (135° F. for 15 min.)	9	196	175	21	11	22	13	4	2	3	0	0	11	
5	Ordinary seed. No treatment	10–12	496	457	39	8	50	22	14	3	10	1	0	10	
6	Seed mixed with smut	13–14	356	319	37	10	43	24	8	3	6	2	0	12	
7	Seed mixed with smut. Plants mutilated June 13	15	160	148	12	8	13	5	4	0	4	0	0	8	
8	Seed treated with hot water (135° F. for 15 min.), but planted very late, June 13	16 18	377	361	16	4	20	5	9	0	2	4	0	5	.5
9	Ordinary seed. No treatment, but planted very late, June 13	19 20	253	241	12	5	12	4	6	0	0	2	0	5	

TABLE 22. FIELD CORN EXPERIMENTS WITH SMUT,—PASTURE BROKEN ONE YEAR, SAME AS IN TABLE 16, 1895. 1896

1	Ordinary seed planted early. Plants mutilated July 8	**11-12**	**211**	**187**	**24**	**11**	**27**	**16**	**6**	**0**	**3**	**2**	**0**	**13**	13
2	Seed treated with hot water (133–4° F. for 15 min.), but planted very late, July 8	22-23	194	193	1	½	1	1	0	0	0	0	0	½	1
3	Ordinary seed, planted very late, July 8	33-34	171	168	3	2	4	0	1	0	0	3	0	2	

manure over it, a condition which was favorable for the development of sporidia. This alone, however, cannot explain the result, for the rest of the land which had been planted on time and so matured a fair crop as to growth, etc., was not unusually smutty. Plat 16 shows that counts made in this gave an average of only thirteen outbreaks per hundred stalks. Second, the corn being planted late with other unfavorable conditions for development did not produce a crop that had the resistant powers it would have had otherwise. In other words, tissues were not so firm, parts were not so securely wrapped while young, etc. This general weakness was shown by the corn being more easily blown down. These are conditions that would favor the sporidia, when present, in being carried down to the susceptible parts and in being able to infect them. One can not conclude, however, that such unfavorable conditions to the corn as are produced alone by late planting will give a smutty crop, since the next year corn planted on the same land and growing even more weakly (Plats 2-3, Table 22) gave an unusually small amount of smut, and the general result of all the other experiments with unusually late plantings shows less smut than in corn planted on time. In this second year on the pasture land, however, there was lacking the fresh manure of the first year, and none of the other late plantings were on land to which manure had recently been applied.

The second badly smutted corn was that recorded in Table 17, in which the smutty outbreaks averaged twenty-six per hundred stalks. This land was selected because it had quite a smutty crop on it the year before and it was desired to see what influence this would have on the next crop. The four different treatments tried with the corn did not show any positive results. There were, however, several things peculiar about the occurrence of the smut. In the first place it appeared in small outbreaks on all parts of the plants. These were more generally distributed than those found in any of the other experiments. The tassels and leaves which ordinarily are not subject to smutty outbreaks contained an unusually large number. These were often inconspicuous. For instance there were found several stalks that had but a small outbreak in a single flower in the top of the tassel. This condition of affairs forced the conviction at the time that infection had been aerial and local and not through the germinating seeds as supposed when the experiments were planned. Another peculiarity was the wide difference in number of outbreaks between plats one and four, known not to be due to treatment and certainly not an accidental variation, as all the rows in plat one gave a low number of outbreaks, while nearly all of those in plat four gave a high number. The data obtained also showed that the smut gradually increased from plat one toward plat four, even showing this increase in the outbreaks on leaves and panicles. This discovery led to the supposition at first that manure had been used on or near the worst

TABLE 23. FIELD AND SWEET CORN EXPERIMENTS WITH SMUT, USING LAND PLANTED BEFORE WITH CORN. 1897.

Plat.	Treatment.		Rows.	Total stalks.	Free stalks.	Smutty stalks.	% smutty stalks.	Smutty outbreaks.	Average outbreaks, etc. 7						
									In lower nodes.	In upper nodes.	In leaves.	In maturable ears.	In tassels.	In aerial roots.	Rate of outbreaks per 100 stalks
1	Ordinary seed. No treatment	Field corn.	1	91	85	6	7	6	3	1	0	1	0	1	7
*2	Same as 1, but smut of last year in water sprayed on young parts of tassels and ears when tassels were mostly extended, July 30		**2**	**88**	**41**	**47**	**54**	**50**	**3**	**0**	**0**	**45**	**2**	**0**	**57**
3	Same as 2, but smut from this year's field crop in water		**3**	**73**	**44**	**29**	**40**	**31**	**4**	**0**	**0**	**27**	**0**	**0**	**42**
4	Same as 3, but spores in manure water		**4**	**80**	**46**	**34**	**43**	**35**	**4**	**0**	**0**	**31**	**0**	**0**	**44**
5	With seed was placed a handful of moist old horse manure containing an abundance of smut placed in it last fall		5-6	152	142	10	7	11	9	0	0	1	1	0	7
6	With seed was placed a handful of moist fresh horse manure containing an abundance of smut just mixed with it		7	83	77	6	7	7	3	1	0	1	2	0	8
7	Same as 6, using field corn smut	Sweet corn.	8	116	115	1	1	1	0	0	0	1	0	0	1
8	Same as 2, but using sweet corn smut of this year		9	95	92	3	3	3	0	0	0	2	1	0	3
9	Same as 2, using field corn smut		10	94	93	1	1	1	0	0	0	1	0	0	1
10	Ordinary seed. No treatment		11	87	87	0	0	0	0	0	0	0	0	0	0

*In case of Plats 2, 3, 4, 8 and 9, the embracing leaves and husks were torn open to spray spores on ears.

infected side, but investigation showed that such was probably not the case. It was found, however, that this corn and plats on either side of it had also been used as experiment in corn culture, in which part of the corn was plowed shallow and deep once a week, and the rest the same but twice a week. This may possibly explain why the plats were so unevenly smutted. In this case then the probable local causes were, first, land that had an unusually smutty crop on it the year before and so supposedly an unusually large number of germs in the ground; and second, an unusually frequent stirring of part of the land.

Conclusions. From the results of the foregoing experiments and observations, the following conclusions are drawn relative to this fungus and its host under conditions that prevail in nature. 1. Corn smut is more entirely dependent upon its sporidia for infection than any of the other smuts of cereals. 2. The spores, often germinate in water but much more easily in nutrient solutions and the sporidia formed, especially on exposure to air, greatly increase in numbers. There is every reason for believing with Brefeld that manure is a prominent agent in nature for their multiplication. 3. Infection takes place rarely, if at all, through the germinating seed, and so seed treatment has proved without effect even in degree. 4. Infection is aerial and local (points first discovered by Brefeld). 5. Wind serves as the carrying agent of the sporidia to the plant, but rain and dew no doubt help to bring them down to the points where infection can take place. 6. Because of the above conditions land can not be selected that will be entirely free from smut. 7. Avoiding the use of manure, selecting land not having a smutty crop the year previous, and properly tending to the crop, however, should result in a minimum amount of smut. 8. Mutilation of the plants at certain stages in their growth tends to increase the amount of smut, especially if germs be abundant at the time of mutilation. 9. Unfavorable conditions for the normal development of the host by leaving its parts improperly protected against infection and resistance are favorable conditions for development of smut if germs are present in sufficient numbers. 10. Observation indicates that different varieties of corn vary in their protection from or resistance to smut, though how much this amounts to has not been determined by any experimental work.

GRAIN SMUT OF SORGHUM AND BROOM-CORN.

Cintractia Sorghi-vulgaris (Tul.) Clinton.

Life History. One of the most prominent effects of this fungus on its hosts is the transformation of the parts that normally become the flowers into small smutted kernels. An examination of one of these outbreaks shows it to consist of a membrane, that in time becomes dry and ruptured, filled with a dusty mass of spores, except at the center, where

TABLE 24. FIELD CORN EXPERIMENTS WITH SMUT, USING CULTIVATED GROUND NOT IN CORN YEAR BEFORE. 1898.

Plat.	Treatment.	Rows.	Total stalks.	Free stalks.	Smutty stalks.	% smutty stalks.	Smutty outbreaks.	Average outbreaks (omitting those due to detasseling), etc. 10						
								In lower nodes.	In upper nodes.	In leaves.	In ears.	Where detasseled.	In tassel.	Rate of outbreaks per 100 stalks.
1	Ordinary seed. No treatment	1– 2	82	62	20	25	21	4	1	0	2	**14**	0	26
2	As in 1, but young parts sprayed with smut in water when about six inches high, June 18	3– 4	85	71	14	16	17	2	0	0	3	**12**	0	20
3	As in 2, but smut in manure water	5– 6	83	56	27	33	32	8	0	0	4	**20**	0	39
4	Ordinary seed. No treatment	7–12	258	188	70	27	75	14	3	1	14	**43**	0	29
5	Mutilated plants when six inches high, June 18	13–14	81	58	23	28	27	3	2	0	4	**18**	0	33
6	As in 5, but also sprayed with spores in water	15–16	85	58	27	32	30	8	1	0	5	**16**	0	35
7	As in 5, but also sprayed with spores in manure water	17–18	92	71	21	23	22	4	0	0	4	**14**	0	24
8	Ordinary seed. No treatment	19–24	259	199	60	23	71	12	8	0	7	**42**	2	27
9	Ears when rather old (passing from milk to dough stage) mutilated, Aug. 25	25–26	97	67	20	21	21	3	2	0	2	**14**	0	22
10	As in 9 but also spores in water sprayed on these mutilated places	27–28	84	72	12	14	18	8	0	0	3	**7**	0	22
11	As in 9 but also spores in manure water sprayed on these mutilated places	29–30	86	71	15	17	16	4	0	0	2	**10**	0	19
12	Seed taken from smutted ears very close to the outbreak and more or less imperfect and moldy	31–32	46	39	7	15	8	1	1	0	1	**5**	0	17
13	Seed taken from smutted ears but as far away from outbreak as possible. Seed sound	33–34	76	64	12	16	12	2	0	0	3	**6**	1	16

the plant tissues have formed a hard columella. All or only part of a panicle may have its flowers thus transformed.

The spores are generally sub-spherical and about 5-8μ in diameter. Seen in mass they have a dark olive brown color. The cell walls are smooth, but frequently have a papillate appearance, due to condition of protoplasmic contents. Germination takes place very readily at any time of the year, its character depending somewhat on medium used. In general it consists in the production of a septate germ-thread several times the length of the spore, with the frequent formation of knee-joints at the septa. If in water the pro-mycelium is apt to form few sporidia and more infection threads, but if in nutrient solution there is produced, while it lasts, an abundance of sporidia.

Infection takes place by the penetration of the infection threads of the spores or sporidia into the very young tissues of the germinating seed, danger from this being over by the time the plants appear above ground. The mycelium formed from the infection threads develops toward the growing point of the plant, and if successful in reaching this follows its upward growth, developing most abundantly in the pith cells between the bundles. In this way the fungus makes a growth through the eight to ten feet of stalk without even showing its presence. With the formation of the flowering parts, however, the fungus threads encroach more severely on the very young plant cells and form an abundance of fertile threads. From these are developed the spores, with the result that instead of the flowers appearing on the panicles their place is taken by the seed-like bodies previously described. A careful study of the spores, their germination, and spore formation shows that the fungus on both broom-corn and sorghum is the same.

Damage. In the investigations with broom-corn (see bulletin 47) it was found that the injuries caused by this smut were as follows: Inferior brush, the irregular rays spread out on a thickened axis instead of uniform ones starting from a single point; the destruction of the seed; the blackening of brush by the spores settling on it when handled damp. It was also learned that while ordinarily fields did not have a very high per cent of smut that occasionally, especially in certain seasons, they became quite smutty, and that as a whole this was the worst fungous pest of broom-corn.

In the work with sorghum it has been the endeavor to obtain a quite exact knowledge of the action of the fungus on this host. Sorghum, like broom-corn, is not one of our general agricultural plants, though it differs from that in being cultivated more widely over the state. This being the case it has been difficult to get an exact idea of the occurrence of the smut. It seems, however, to be much the same with this as with broom-corn; that is, as a general thing the smut is not very abundant or is entirely absent, but in some fields and in certain seasons the amount

may be considerable. The abundance with which it may sometimes occur was shown in 1897 in an examination of the fields of the L. W. Cushman Syrup Company of Urbana. An examination of several of their large fields showed the following results:

No.	*Variety.*	*Total counts.*	*Smutty.*	*% Smutty.*
1	White amber	1500	480	32
2	Orange	1500	66	4
3	Orange	1500	106	7
4	.....	1500	132	9

As the white amber field was the largest it can be seen that in this case the damage must have been considerable if the smut had a very injurious effect on its host.

EXPERIMENTS.

Experiments to determine Nature of Injury. It was to determine the exact effects of this smut on sorghum that an extended series of observations and experiments was made during 1897-8, the results of which are given in Table 25. In explanation it may be said that the experiments were conducted with the orange and white amber varieties of sorghum, the first year the cane being selected from the fields of the L. W. Cushman Syrup Co., and the second year from a special plat grown on the Experiment Station grounds from very smutty seed, so as to make the number of smutty and free canes as nearly equal as possible. Considerable care was used in the collection of smutted and free canes so that any difference that was shown between the two lots would be entirely due to the fungus. The canes were uniformly cut on the afternoon of one day and the measurements and weights taken. The next morning they were carried to a small mill, the juice extracted, measured and samples taken, which were then turned over to the Station chemist, Dr. Hopkins, who made the analyses for sugar content that afternoon, using the official German method.

From the total weights and measurements the following averages are obtained:

Average weight per 100 orange free canes (panicles on)	78	lbs.
" " " smutty canes (")	57	"
Average weight per 100 white amber free canes (panicles on)	68½	"
" " " smutty canes (")	47	"
Average weight per 100 free orange panicles	13	"
" " smutty orange panicles	4	"
Average weight per 100 free white amber panicles	7	"
" " smutty white amber panicles	3	"
Average length of the orange free canes	8.15	ft.
" " " smutty canes	7.72	"
Average length of the white amber free canes	8.64	"
" " " smutty canes	8.19	"
Average length of the free orange panicles	7.9	in.
" " smutty orange panicles	6.4	"

Average length of the free white amber panicles	9.8	in.
" " smutty white amber panicles	8.4	"
Average quantity of juice per 100 orange free canes	16.2	qts.
" " " " smutty canes	10.3	"
Average quantity of juice per 100 white amber free canes	15.4	"
" " " " smutty canes	10.1	"

An inspection of these averages shows that the free cane (panicles on) of both varieties was about one and a half times as heavy as the smutty. The free panicles of the orange were over three times as heavy as the smutty, while with the white amber they were over twice as heavy. This was due to the prevention of seed formation by the smut, and as the orange is much more prolific in this respect than the other the difference between its free and smutted panicles is consequently greater. This destruction of seed is undesirable, as it is sometimes saved for feeding or sale and has a commercial value of about fifty cents a bushel. The effect of the fungus is not only shown in the weight of the canes, but also in their length, as the smutty of both varieties averaged about five inches shorter than the free. The greatest proportion of this shortening took place in the panicles, as in both cases these averaged about an inch and a half shorter in the smutty canes; that is, between a third and a fourth of the shortening occurred in the panicles, while they represented only about a tenth to a twelfth of the total length. The smutty canes were also apparently more slender than the free, and, while no measurements were made to determine this, the smaller ratio of their length to their weight as compared with the free indicates that such was the case.

The quantity of juice from each variety was one and a half times as great from the free cane as from the smutty. This was a very little larger proportion in either variety than the weight of the free canes (panicles off) was to the weight of the smutty canes. Here then was an injury that was of considerable importance, as the juice is the object for which the plant is raised, and we find that the fungus has had considerable effect in reducing it. It is also seen that this loss is caused chiefly by the reduction in the size of the plants rather than by a reduction in the relative amount of their juice.

The following table shows the action of the fungus on the total sugar content of the smutty plants as compared with the free in the cases where comparisons can be made:

	White amber.				*Orange.*			
Date.	*Smutty.*	*Free.*	*Difference.*		*Smutty.*	*Free.*	*Difference.*	
Sept. 28 9, '97.	8.7%	8.2%	0.5%		9.5%	7.5%	2.0%	
" "	8.9	8.3	0.6		10.6	6.2	4.4	
" "	....	....	....		10.4	7.2	3.2	
Oct. 1, "	....	....	....		10.5	6.6	3.9	
" "	....	....	....		11 5	6.6	4.9	
Sept. 7, '98.	10 1	9.5	0.6		9.5	8.2	1.3	
14, "	11.6	9.6	2.0	1.1	10.9	9.4	1.5	1.1
21, "	11.5	10 8	0.7		11.3	10.9	0.4	
28, "	12.4	12.2	0.2		11.5	11.3	0.2	
Oct. 5, "	11.7	10 8	0 9	0.7	10.6	11.3	—0.7	—0.4
12, "	12.3	11.3	1.0		12.1	12.7	— .6	

An examination of this table shows that the smutty cane gave a higher per cent. of sugar in seventeen out of the nineteen analyses compared and in the two cases where it was higher in the free the difference was slight. It also shows that the difference in favor of the smutty cane was quite variable, sometimes being inconspicuous and in other cases very marked, the average difference being 1.4%.

The first analyses were of orange cane that was hardly mature enough for sorghum making, and these showed such strikingly higher percentages in favor of the smutted cane as to arouse suspicion as to their correctness, and so they were repeated a few days later but with the same results. The analyses made with white amber at that time, however, showed but small differences in favor of the smutted cane. This variety was then perhaps somewhat beyond its prime for factory use. This difference between the two varieties was interpreted to be due at least in part to the difference in their maturity, and the fact that the sample of the orange cane selected in the shade of some trees, and so the least mature, had the greatest difference in favor of smutted cane gave some reason for this belief.

In the second year's work it was planned to have anaylses made of each variety at different dates extending beyond the season of sorghum making at both ends, to determine, if possible, whether maturity of cane had anything to do with this variation. While the first analyses were made much earlier than the previous year, yet on account of season or earliness of planting the cane was so far advanced that it is doubtful if they were made soon enough to bring out the greatest difference, especially in the orange variety. An inspection of the preceding table shows that on the whole there was a general increase in the per cent. of sugar in both the smutty and free cane from the first to the last, but that as the season advanced the difference between the two diminished.

In order to have some check on the method of collection and analysis, duplicate collections of both smutty and free canes were taken on two occasions, under as nearly as possible the same conditions, to see if the sugar content between these would be as variable as between the smutty and free lots. In the first of these collections (Table 25, 8 with 10 and 9 with 11) the results ran very close together, but in one case in the second trial (42 with 43 and 44 with 45) there was a difference of 1.2%. These checks seem to indicate that the natural variation due to collection, etc., would not average a half per cent., not enough to account for the almost uniformly higher percentages that the smutty lots gave.

We are inclined to believe that this difference in per cent. of sugar in smutty and free cane is due to the action of the smut in preventing seed formation. This operation is an expensive one to the plant, and apparently at the time, is carried on at a greater cost to the sugar content than it would require to form smutty panicles. If this is true it

explains why the smutty panicles have a higher sugar content during seed formation and gradually lose this as the seed matures. It also explains why the orange variety gave such wide differences, at certain periods, in favor of the smutted cane, since here the production of seed in the free panicles is much greater than with the white amber. There seems to be some difference of opinion, however, concerning effect of seed production on sugar content, as determined by comparison of normal cane with that from which the seeds or panicles had been removed as soon as appearing. Professor Weber, while connected with this University, made some studies on this question and claimed to have found a difference of 4% in favor of topped cane. Later and much more extended experiments were carried on by Collier and by Wiley of the U. S. Dept. of Agr. The sum total of their analyses shows but little difference between ordinary and topped cane. These analyses were evidently chiefly made during what would be the syrup making season and so were not usually early enough to show the first effect of topping, though from data presented one finds by grouping the earlier and the later analyses together that the former show a difference in favor of topped cane while in the latter it is very slight. The results of these analyses, then, are not contradictory to the belief that at first the seed is produced at a cost of sugar content, though topping, as with smutting, may not prove of final benefit.

Conclusions as to Effect of Smut on Sorghum. The action of this smut on its host, as gleaned from the above investigations seems to be as follows: From the time of infection of the germinating seed to time of seed production, that is during growing season, the smutted plant has to furnish food to the fungus for its growth and this, with other undetermined effects of fungus on host, is done at a cost to the weight and size of its cane. This injury becomes most exaggerated in the panicles, because it is here that the fungus becomes most vigorous in its development, actually preventing the formation of the seed. The production of seed, however, is a costly process for a plant, and in this case requires more food material than it does to form the smutted panicles, hence the smutted cane may show a higher per cent. of sugar at this stage than the free. With maturity of seed, however, this difference disappears so that at the proper season for sorghum making it is of little economic importance. On the other hand, however, the quantity of juice in the smutted plant is less than in the free, being in about the same proportion as the weight of the cane is to that of the free. This ratio is maintained about the same during the whole season. From an agricultural standpoint, then, the presence of smut is of importance because it both destroys the seed and lessens the yield of sorghum that is finally made.

Miscellaneous Experiments. That the smut on sorghum and broom-

TABLE 25. EXPERIMENTS CONDUCTED TO DETERMINE EFFECT OF SMUT UPON SORGHUM. 1897-8.

No.	Date of cutting cane.	Variety.	% of smut in field or row.	Conditions of collection.	Average length, panicles on, feet.	Average length, panicles off, feet.	Weight of cane, panicles on, pounds.	Weight of cane, panicles off, pounds.	Yield of juice, quarts.	% Cane sugar.	% Invert sugars.	Total sugars.
1	Sept. 28, 1897.	White amber..	32	Sample of juice taken from quantity at factory						9.2	1.1	10.3
2	" "	Orange.....	4	100 small smutted canes, taken as found in row						9.4	.1	9.5
3	" "	"	4	100 small free canes as near size and place of those in No. 2						7.6	.1	7.5
4	" "	"	4	100 large smutted canes taken as found in row						10.4	.2	10.6
5	" "	"	4	100 large free canes as near size and place of those in No. 4						5.8	.4	6.2
6	" "	"	4	100 consecutive smutted canes taken as found in row	7.21	6.65	57½	53		10.2	.2	10.4
7	" "	"	4	100 free canes from same row as 6, 25 taken from either end and 50 from middle	7 43	6.70	76½	62½		6.5	.7	7.2
8	Sept. 29, "	White amber..	32	50 consecutive smutty canes taken as found in row	8.24	7.46	27½	25½	5½	7.8	.9	8.7
9	" "	" "	32	50 consecutive free canes taken same row and place as 8	8.84	7.97	37½	34½	8½	7.8	.4	8.2
10	" "	" "	32	50 consecutive smutty canes taken as found in same row as 8, but beyond	8.37	7.68	27	25½	6	8.4	.5	8.9
11	" "	" "	32	50 consecutive free canes taken as found in same place as 10	8.79	7.96	35	31½	7¾	8.3	0	8.3
12	" "	" "	32	Sample of juice taken from quantity at factory						8.3	2.1	10.4
13	Oct. 1, "	Orange.....	4	50 smutted canes taken as found in row. Leaves killed by frost			29	27½	4½	10.2	.3	10.5
14	" "	"	4	50 free canes taken same row and place as 13. Leaves killed by frost			38	31½	6¾	6.5	.1	6.6
15	" "	"	4	50 smutted canes taken as found from several rows in shade. Leaves still green			27½	24	4½	11.2	.3	11.5
16	" "	"	4	50 free canes, one being taken from each place, one in 15 was taken. Leaves still green			35½	27	6	5.5	1.1	6.6
17	" "	"	4	Imperfect sampling juice of No. 13						10.5	.0	10.5
18	" "	"	4	Imperfect sampling juice of No. 14						5.9	.3	6.2
19	Sept. 7, 1898.	White amber..	45	50 smutted canes taken as they came in the row	7.76	7.09	21	20	5⅓	9.8	.3	10.1
20	" "	" "	45	50 free canes taken as they came from same place as 19	8.55	7.71	30½	27	8	8.8	.7	9.5
21	" "	Orange.....	40	50 smutted canes taken as they came in the row	7.84	7.31	26	24	6½	8.5	1.0	9.5
22	" "	"	40	50 free canes taken as they came from same row and place as 21	8.02	7.51	39	33	9½	7.0	1.2	8.2
23	" "	"	0	50 free canes taken from row in which smut had been prevented by hot water treatment			34½	30	8⅓	7.1	1.2	8.3

TABLE 25.—(*Continued*)

24	Sept. 7, 1898.	Golden orange.	0	Sample of juice as running from mill						8.2	1.6	9.8
25	Sept 14, 1898.	White amber..	40	50 smutty canes taken as they came in row	8.13	7.45	23	21½	5¼	10.7	.9	11.6
26	" "	" "	40	50 free canes taken as found in same place as 25	8.48	7.70	31½	27½	7⅛	9.0	.6	9.6
27	" "	Orange	38	50 smutty canes taken as they came in row	7.95	7.41	29½	27½	7⅛	9.3	1.6	10.9
28	" "	"	38	50 free canes taken as found in same place as 27	8.44	7.80	40	34	9⅕	7.4	2.0	9.4
29	" "	"	0	50 free canes, smut prevented by hot water treatment			37½	31½	8⅕	8.9	2.1	11.0
30	Sept. 21, "	White amber..	50	50 smutty canes taken as they came in row	8.34	7.68	28	26½	5⅘	10.7	.8	11.5
31	" "	" "	50	50 free canes taken as found in same place as 30	8.48	7.68	38	32½	8½	9.7	1.1	10.8
32	" "	Orange	45	50 smutty canes taken as they came in row	7.55	7.03	30	27	5⅘	9.9	1.4	11.3
33	" "	"	45	50 free canes taken as found in same place as 32	8.24	7.62	43	35	9⅕	9.1	1.8	10.9
34	Sept. 28, "	White amber..	50	50 smutty canes taken as they came in row	8.22	7.54	25	24	4⅘	11.2	1.2	12.4
35	" "	" "	50	50 free canes taken as found in same place as 34	8.56	7.67	33	29½	6⅘	10.4	1.8	12.2
36	" "	Orange	45	50 smutty canes taken as they came in row	7.59	7.09	27½	25	5⅕	9.2	2.3	11.5
37	" "	"	45	50 free canes taken as found in same place as 36	8.20	7.52	42	35	8⅔	9.3	2.0	11.3
38	Oct. 5, "	White amber..	60	50 smutty canes taken as they came in row	8.27	7.59	24½	23	4⅕	10.8	.9	11.7
39	" "	" "	60	50 free canes taken as found in same place as 38	8.81	8.05	35½	31½	7⅕	9.9	.9	10.8
40	" "	Orange	30	50 smutty canes taken as they came in two rows	8.18	7.67	29½	27½	6⅕	9.9	.7	10.6
41	" "	"	30	50 free canes taken as found in same place as 40	8.56	7.82	39½	34	8⅛	10.5	.8	11.3
42	" "	"		25 smutty canes selected at random in two rows			12	11	1⅞	10.7	.7	11.4
43	" "	"		25 smutty canes from same place as 42. Check			12	11	2	10.8	.2	11.0
44	" "	"		25 free canes selected at random in two rows			24	20	4⅘	10.9	.7	11.6
45	" "	"		25 free canes from same place as 44. Check			23½	19½	4¼	11.6	1.2	12.8
46	Oct. 12, "	White amber..		50 smutty canes taken about as they came in two rows			24	22½	4⅘	11.7	.6	12.3
47	" "	" "		50 free canes taken same place as 46			33	30	7⅕	10.6	.7	11.3
48	" "	Orange		50 smutty canes taken about as they came in two rows			30	28	5⅔	12.0	.1	12.1
49	" "	"		50 free canes taken same place as 48			39	33½	7⅕	11.6	1.1	12.7

corn is but one species is proved by the following cross infection experiments made in 1898. The broom-corn did not give so high a per

TABLE 26. EXPERIMENT SHOWING IDENTITY OF BROOM-CORN AND SORGHUM SMUT.

Plat.	Treatment given seed.	Total stalks.	Smutty.	% smutty.
1	Broom-corn seed given hot water treatment.	340	0	0
2	Same as 1 but mixed with sorghum smut afterwards..	284	46	16
3	Sorghum seed given hot water treatment....	623	0	0
4	Same as 3 but mixed with broom-corn smut afterwards.....	648	262	40

cent. of smutted plants because its seeds were protected by the glumes, while those of the sorghum were naked, a condition that would make considerable difference in the ability of the smut to infect the germinating seed.

In the work with oats it was shown that time of planting may have something to do with determining the per cent. of smut. Experiments of this nature were also carried on with broom-corn during the year 1897. A row each of smutty seed, one and four years old, was planted every week during the broom-corn season and extending beyond it in the later plantings. These experiments (Table 27) show that smut kept for four years in a dry warm room still germinated sufficiently to infect a goodly number of plants, though its vitality as well as that of the seed was greatly reduced. It was also shown, as with the oats, that if the season of planting is extended beyond its natural limits, successful infection is greatly reduced. For instance, plantings made during May averaged 38% smutty with the one year old seed and 12% with that four years old, while those made out of season, June 10-28, averaged only 18% with the former and 2% with the latter seed. There was,

TABLE 27. RELATION OF TIME OF PLANTING TO AMOUNT OF SMUT IN BROOM-CORN.

Planted.	Seed.	Total stalks.	Smutty stalks.	% smutty.	Seed.	Total stalks	Smutty stalks.	% smutty.
May 6....	4 years old	.....	.....	.....	1 year old.	325	107	33
" 10....	"	75	10	13	"	286	83	29
" 17....	"	72	15	21	"	242	143	59
" 24....	"	155	15	10	"	232	77	33
" 31....	"	140	9	7	"	180	65	36
June 10....	"	97	4	4	"	163	33	20
" 15....	"	119	0	0	"	221	33	15
" 21. ..	"	143	6	4	"	263	63	24
" 28....	"	132	0	0	"	214	26	12

likewise, considerable variation in the plantings during the normal season. In both of these cases the amount of moisture in the soil seems to have been one of the primary causes of this variation, as there was a

difference in this respect even during May, while in June the moisture was considerably reduced.

It has been claimed by some writers that the action of smut on certain hosts is to hasten the time of appearance of the smutty panicles. An effort was made to determine if this were true in the case of broom-corn. Counts of the smutty and free panicles were made on a small plat four times during the period of protrusion, as shown in Table 28. These counts did not reveal any marked difference in their time of appearance.

TABLE 28. TIME OF APPEARANCE OF SMUTTY PANICLES OF BROOM-CORN.

Condition.	Sept 3.	Sept. 7.	Sept. 13	Sept. 23.
Total panicles out	10	53	168	214
Smutty panicles out	1	8	20	26
Per cent. smutty	10	15	12	12

Prevention Experiments. It was shown in the experiments conducted in 1895-6 with grain smut of broom-corn (see bulletin 47) that the fungus could be prevented by the hot water treatment. During 1897-8 further experiments were conducted, especially for comparing the hot water with different treatments that had proved successful with other plants. The results are given in Table 29.

TABLE 29. PREVENTION EXPERIMENTS WITH BROOM-CORN SMUT. 1897-8.

Plat.	Treatment given seed.	Total.	Smutty.	% smutty.
1897.				
1	Check plat. Untreated. Plants in shade	426	280	66
2	Hot water, 135° F. for 15 minutes	1794	7	0.4
3	Potassium sulfid, 1 lb. to 12 gals. water	1749	17	1.0
4	Ceres pulver, 1 lb. to 12 gals. water	1337	20	1.5
5	Copper sulfate, 1 lb. to 5 gals. water	930	0	0
6	Check plat. Untreated. Plants in sun	1458	696	48.
1898.				
1	Check plat. Untreated	641	158	24.6
2	Potassium sulfid, 1 lb. to 10 gals. water	801	32	4.
3	Ceres pulver, 1 lb. to 10 gals. water	842	30	3.6
4	Copper sulfate, 1 lb. to 10 gals. water	741	81	11.
5	Corrosive sublimate, 1 lb. to 50 gals. water	587	110	18.7
6	Formalin, 1 lb. to 50 gals. water	578	141	24.4
7	Hot water, 133°–127° F. for 15 minutes	870	144	16.5

In these treatments broom-corn seed that had been mixed with smut was used, and in all the cases, except the hot water, the method was to sprinkle the seed thoroughly with the solution used, letting it stand a few days before planting. In 1897 all of the treatments were quite successful. The next year, however, they were not quite so satisfactory. The sprinkling was not so thorough this time, and, in the cases of the copper sulfate, corrosive sublimate, and formalin, the solutions were evidently not used strong enough. The hot water treatment,

too, was made at a lower temperature than the year before and so was less successful.

In 1898 the same treatments that were used with broom-corn were also tried with sorghum. In this case the treatments were much more efficient. This is readily explained by the fact that this seed was hulled, while the broom-corn seed was enclosed by the glumes, which condition served to protect the smut germs from the action of the fungicides. The results, Table 30, show that even then the formalin solution at least was not strong enough.

TABLE 30. PREVENTION EXPERIMENTS WITH SORGHUM SMUT. 1898.

Plat.	Treatment given seed.	Total stalks.	Smutty stalks.	% smutty.
1	Check plat. Untreated.....	1084	479	44.
2	Potassium sulfid, 1 lb. to 10 gals. water.....	956	13	1.3
3	Ceres pulver, 1 lb. to 10 gals. water.....	1167	9	.8
4	Copper sulfate, 1 lb. to 10 gals. water.....	1272	10	.8
5	Corrosive sublimate, 1 lb. to 50 gals. water..	1160	31	2.6
6	Formalin, 1 lb. to 50 gals. water.....	934	85	9.
7	Hot water, 135°–7° F., for 10 minutes.....	177	2	1.1
8	Hot water, 132°–1° F., for 10 minutes. ...	870	136	15.

The necessity of treating sorghum or broom-corn when using hot water at a temperature of 135°F. for 15 minutes was also shown by some wholesale treatments made for the Cushman Syrup Company. Six bushels were treated, a bushel at a time. The first treatment was made at about 130°F. for 10 minutes. As the glumes were all off the seed it was feared that a higher temperature might injure its germination. Some germination tests, however, showed that this was nowhere near the danger point. The rest of the seed was treated at about 132°F. for 10 minutes. Even this was too low, as is shown (Table 30, plat 8) by the presence of 15% of smutty plants, a much lower per cent., though, than in the check lot.

On the whole, hot water treatment of the proper severity seems to be the most satisfactory with the smut of sorghum and broom-corn, and, as there is never much seed used in planting these crops and as the treated seed is easily dried out, it lacks much of the objection made against its use with oats. It is very probable, however, that if stronger solutions of formalin had been used it would also have proved very efficient.

HEAD SMUT OF SORGHUM.*

Cintractia Reiliana (Kühn).

This smut differs greatly from the more common grain smut of sorghum, as it converts the whole panicle into a large irregular mass.

*This species has also been reported a few times in this country as occurring on corn, but so far has not been found in this state on that host. It has been classified with the *Ustilagos*, but examination of the method of spore production shows it to be a *Cintractia*.

At first this is enveloped by a whitish membrane composed entirely of sterile fungous threads. Within this is a dark mass of spores and the harder plant tissues, consisting chiefly of the rays of the panicle, that have not been destroyed. Sometimes the panicle is only partially infected. The membrane soon becomes dingy and the spore mass more of a brown black color. In time the outbreak becomes ruptured and the spores disseminated.

Under the microscope the spores also appear quite different in these two species. Those of the head smut are dark brown, mostly sub-spherical, often with sides somewhat flattened by pressure, and mostly 10-15μ in diameter. Their outer wall is minutely papillate, though sometimes quite obscurely. In the few trials made the spores failed to germinate, but Brefeld says that they germinate easily, producing a three or four celled pro-mycelium and an abundance of sporidia.

Apparently from the experiments of Kellerman, infection takes place through the germinating seed, though the per cent. of infection he produced was rather small. In 1898 field experiments were conducted here with the view of infecting the orange variety of sorghum with this smut. In one case the seed was mixed with an abundance of spores and in others these spores were sprayed in water or manure water on the young parts of the plants when about six inches high. In none of the several hundred plants that matured was any sign of the smut found. It is very likely that the variety used may have had something to do with the negative results, as it was not the same from which the smut was taken and which it was intended originally to use.

This smut was first found in Egypt in 1868 and named by Kühn after its discoverer. It has been reported only once in this state, having been found in a sorghum field in the vicinity of Breeds, in August, 1897. It was rather abundant in that field and seemed to be doing considerable damage. It has been reported in several other places in this country, and in Kansas has been found not uncommon on corn, and while not so frequent on this host as the common smut, it seems to be much more injurious when present.

GRAIN SMUT OF HUNGARIAN GRASS.

Ustilago Crameri, Koern.

In the spikes of the different varieties of cultivated millet (*Setaria Italica*) there is sometimes found a smut which infests the individual flowers. An infected spike much resembles the smutted ones of the related fox-tail grass, though the fungus is really quite distinct and much less common. Generally only the lower parts of the glumes are destroyed, the smut showing through the thin covering membrane here while the upper parts are normally developed. Sometimes the hard

flowering glume and palet escape entirely and then the smut is less conspicuous.

The spores in mass are dark brown, smooth, varying from occasionally irregular oblong or oval to chiefly sub-spherical in shape and from 8-10μ in diameter, with the irregular ones somewhat longer and narrower. Brefeld states that neither in water nor in nutrient solutions do the spores produce sporidia, but instead form a pro-mycelium that becomes septate and branched.

This fungus does not seem to occur frequently in this country, though apparently not so uncommon in some parts of Europe. It has been found but once in this state. This was at Alto Pass, Union County, in August, 1898, where it was discovered in a recently mowed field of German millet, and apparently had not been very abundant in the field. So far as found no preventive experiments have been made against this fungus, unless by Bolley of North Dakota. He recommends the sprinkling method with formalin (1 lb. to 45 or 50 gals. water) as having been successful with a smut of millet.

LEAF SMUT OF TIMOTHY, REDTOP AND BLUE-GRASS.

Ustilago striaeformis (West.) Niessl.

Frequently on timothy and redtop and rarely on blue-grass, there is found in this state in late spring and early summer a smut which occurs in dusty outbreaks on the leaves and sheaths and more rarely in the inflorescence. These dusty patches frequently merge into long ruptures, which, when very abundant, cause the leaves to become badly torn and shredded. Such plants are smaller than the healthy and often, especially in case of blue-grass, are so inconspicuous as to be easily over-looked. Frequently the attack is so severe that the plants do not head out.

The spores in mass have a black brown color, average 10-14μ in diameter, and are chiefly elliptical to sub-spherical in shape, with outer coat covered with prominent echinulations. The fungus is apparently perennial in those hosts that live from year to year, as its mycelium has been found abundantly in the bulb-like bases of timothy and also in the young buds developed from these. This seems to indicate also that infection takes place through the germinating seed. The spores are germinated with difficulty, and out of many trials the writer has been only partially successful a few times, and then mostly with spores from redtop. The germination shows that this is not a Tilletia, as usually supposed, but an Ustilago. The germination so far as it proceeded consisted in the development of a germ thread many times the length of the spore, occasionally giving rise to a branch and becoming septate and empty at the base after it reached a certain development. No sporidia were found. So far as can be learned the reason for considering it a

Tilletia is based on Fischer de Waldheim's observations on spore formation [Pringsheim Jahrbücker **7**:85. 1869]. Niessel [Hedwiga **15**:1. 1876] was first to show identity of forms described by Westendorp and Waldheim, and as he placed the species with Ustilago his nomenclature has been followed.

This fungus is a not an uncommon one both in this country and Europe and has been reported on a number of different wild and cultivated grasses. It sometimes does considerable damage, although it is not an easy matter to determine how much this is. It was found in one case year after year in a timothy field and as it was quite common it evidently did considerable harm. It seems, however, to be most injurious to redtop. In 1898 Mr. Frank Kagy, of Kinmundy, complained of its being very injurious in his fields of this crop, and a later examination showed that it was causing an injury of fully 30% to the plants. Mr. Kagy stated that it had greatly cut down the yield of seed from his fields, at times down to 70 cwt. from the normal 300 cwt. So far as determined there have been no attempts made with seed treatment for prevention of this smut, but from what is known of its life history, such would seem to be a successful means for controlling it.

G. P. Clinton, M. S.,
Assistant Botanist.

EXPLANATIONS OF ILLUSTRATOINS.

Plate A. 1. Hidden smut of oats, *Ustilago levis.* 2. Free panicle. 3. Loose smut of oats, *Ustilago Avenæ.*

Plate B. Experiment in producing hidden smut in oats. 1-2. Plants from plat merely having glumes removed from seed: 1. free plants; 2. smutted plants; total smutty panicles 1 per cent. 3-5. Plants from plat having glumes removed and then mixed with smut spores: 3. free plants; 4. partially smutted plants; 5. wholly smutted plants; total smutty panicles 71 per cent. See Tables 3 and 7. *Ustilago levis.*

Plate C. Smutted panicle of oat grass. *Ustilago perennans.*

Plate D. Smutted spikes of barley showing condition of the loose smut with age. *Ustilago nuda.*

Plate E. Covered smut of barley. *Ustilago Hordei.*

Plate F. 1-2. Loose smut of wheat, 2 showing condition of spikes after spores are worn away. *Ustilago Tritici.* 3. Free spikes of wheat. 4. Spikes of wheat with stinking smut, showing the little change in general appearance caused by this smut. *Tilletia foetens.*

Plate G. Smutty outbreaks from teosinte. *Ustilago Zeæ.*

Plate H. Corn stalks in field showing smutty outbreaks. *Ustilago Zeæ.*

Plate I. Pod corn partially destroyed by smut. *Ustilago Zeæ.*

Plate J. Ears of corn locally infected with smut by mutilating when young and applying spores. *Ustilago Zeæ.*

Plate K 191½ lbs. of smutty outbreaks taken from one-fifth acre plat. See explanation of Table 23, plat 2. *Ustilago Zeæ.*

Plate L. Smutted panicle of sorghum. *Cintractia Sorghi-vulgaris.*

Plate M. Smutted flowers of broom-corn. *Cintractia Sorghi-vulgaris.*

Plate N. Effect of grain smut of broom-corn on panicles, figure with uniform rays showing free panicles while the one with enlarged central rachis showing smutted one. *Cintractia Sorghi-vulgaris.*

Plate O. Head smut of sorghum. *Cintractia Reiliana.*

Plate P. Grain smut of Hungarian grass. *Ustilago Crameri.*

Plate Q. Leaf smut of grasses. 1. redtop, 2. timothy, 3. blue-grass. *Ustilago striaeformis.*

Plate R. Photo-micrographs of spores of various smuts, magnified about 400 diameters. 1. *Cintractia Sorghi-vulgaris* from sorghum. 2. *Ustilago Tritici* from wheat. 3. *Ustilago Zeæ* from corn. 4. *Ustilago striaeformis* from timothy. 5. *Cintractia Reiliana* from sorghum. 6. *Tilletia foetens* from wheat.

Plate S. Germination of spores magnified about 525 diameters: a. spores, b. promycelia, c. sporidia, d. infection threads, e. detached pieces of mycelia, f. knee joints. 1. Germination of *Ustilago Avenae* in $\frac{1}{60}$ % acetic acid 24-48 hours after being placed in liquid. 2. Same as 1 but in distilled water. 3. Germination of *Ustilago levis* in Cohn's modified solution at end of 24 hours. 4. Same as 3 but at end of 2-3 days. 5. Germination of *Ustilago Tritici* in Cohn's mod. sol. 6. Germination of *Ustilago striaeformis* from redtop in $\frac{1}{50}$% acetic acid at end of two days. 7. Same as 6 except spores in Cohn's mod. sol.

Plate T. (a-f. etc., same as in plate S.) 1. Various stages in germination of *Ustilago Zeæ* from corn about 3 days after being placed in water. 2. Same as 1 except spores germinated in contact with air and showing development of air sporidia, 2″ being but slightly magnified. 3. Same as 1 but several days after spores were placed in $\frac{1}{20}$% acetic acid, sporidia forming infection threads. 4. Germination of *Tilletia foetens* several days after being placed on moist plaster of Paris slabs, c′. showing conjugating sporidia.

Plate U. Mycelium of grain smut of broom-corn as shown in cross-sections of infected tissue, 1 magnified about 150 diameters and 2-6 about 500 diameters. 1. Part of section through epicotyl where infection takes place, a. mycelium, b. epidermis, d. central cylinder. 2. Infected cells of 1 more highly magnified. 3. Section through leaf near juncture with epicotyl. 4-6. Mycelium with haustoria in pith cells from various places on plant.

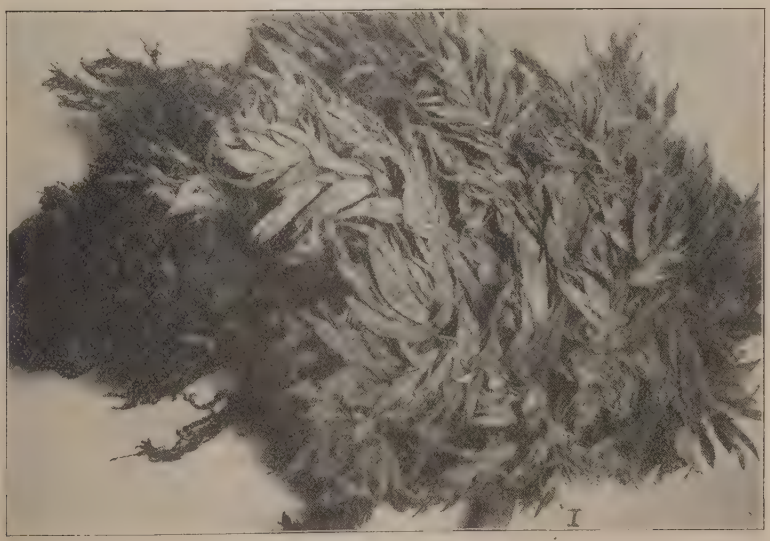
A

B

C
D
E
F

G

H

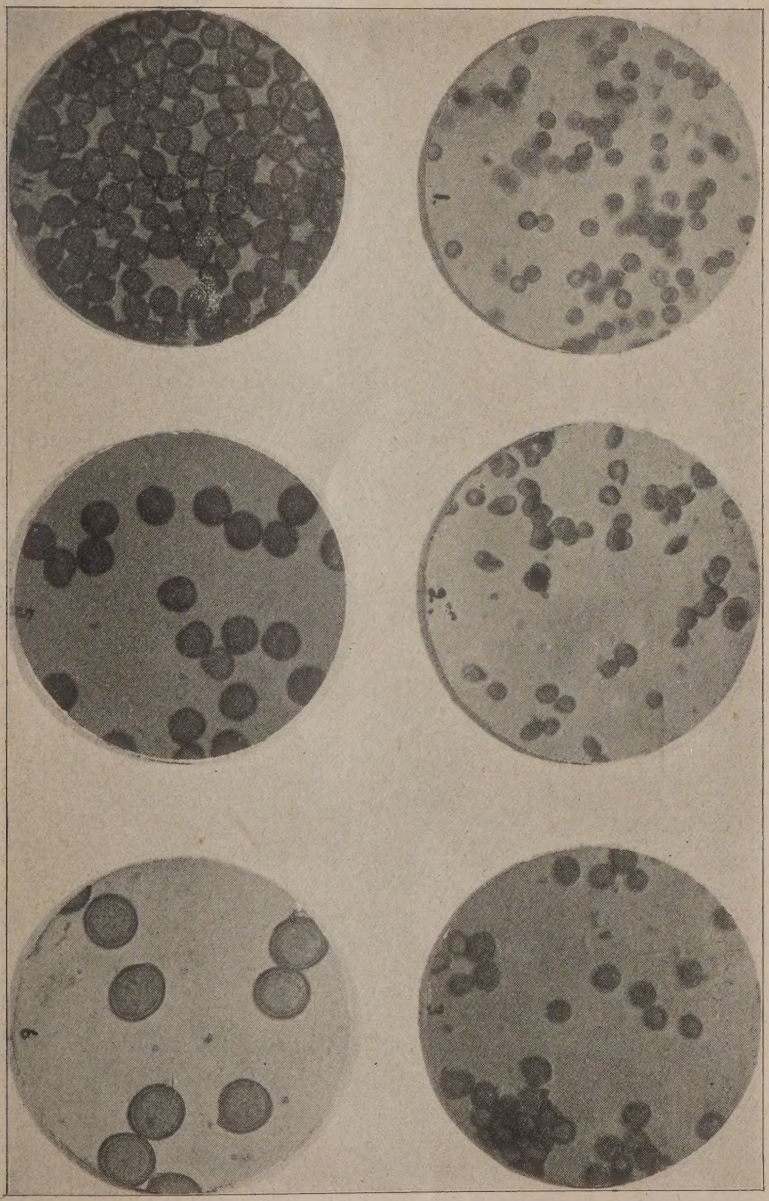

I

K

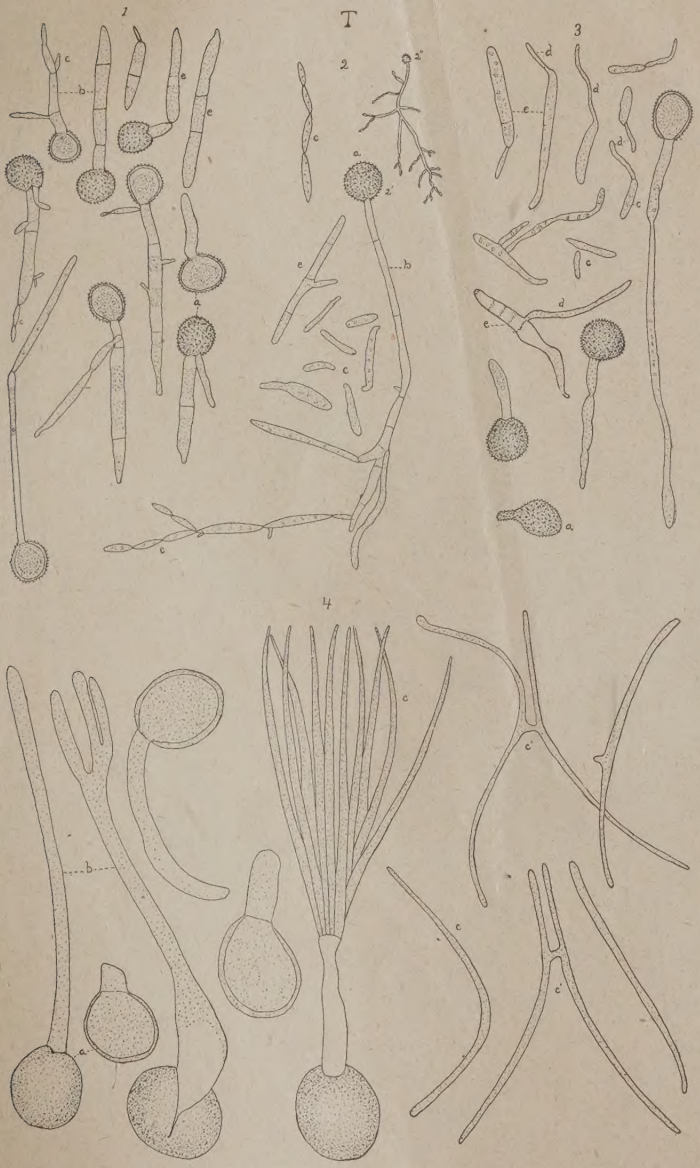
O

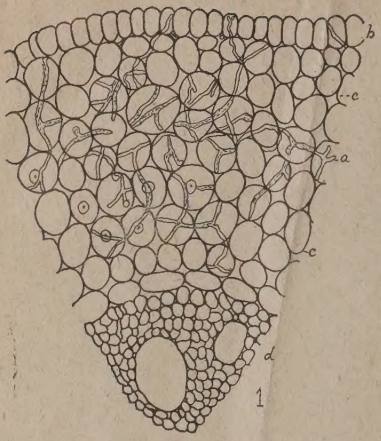
P

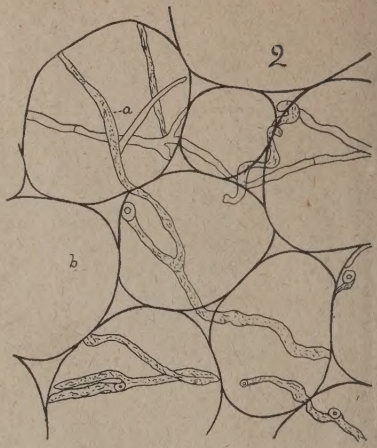
♀
1
2
3

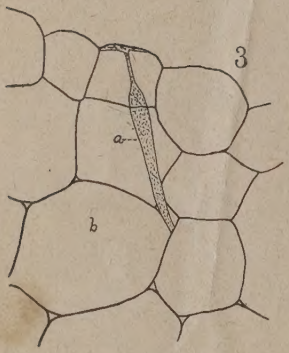


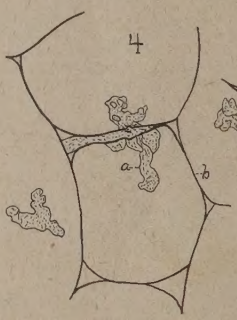
S
1
2
3
4
5
6
7

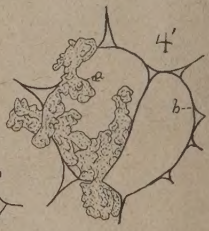

1
2
3
4

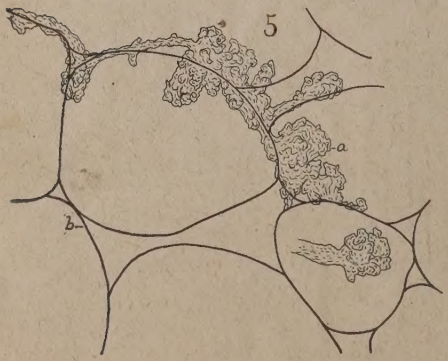

b
c
a
c
d
1

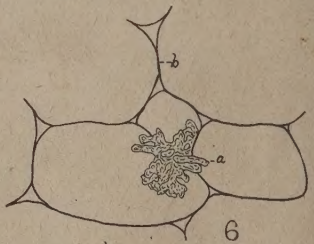

2
a
b

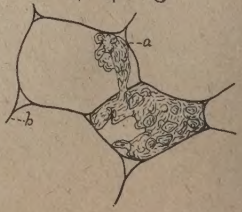

3
a
b


4
a
b


4'
a
b


5
a
b


b
a


6
a
b